Volume XL March-April 1945 Number 2

Economic Geology

and the

Bulletin of the Society of Economic Geologists

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MAY 26 1945
BLACKSBURG, VA.

PUBLISHED SEMI-QUARTERLY

Five Dollars a Year, One Dollar a Copy

THE ECONOMIC GEOLOGY PUBLISHING COMPANY

Printed by Lancaster Press, Inc., Prince and Lemon Streets, Lancaster, Pa.

Entered as second-class matter, March 30, 1906, at the Post Office at Lancaster, Pa., under the Act of Congress of March 3, 1879

Economic Geology

and the

Bulletin of the Society of Economic Geologists

Issued Semi-Quarterly and sent to subscribers on or about the following dates: February 1, March 15, May 1, June 15, August 1, September 15, November 1, December 15.

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ECONOMIC GEOLOGY

VOL. XL MARCH–APRIL, 1945 No. 2

OXIDATION IN A MOLYBDENITE DEPOSIT, NYE COUNTY, NEVADA.

WILSON D. MICHELL.

ABSTRACT.

The Hall Molybdenum deposit near Tonopah, Nevada, has been developed for 1,200 feet in length, and has an average width of 53 feet. It lies in schist along the southern margin of an alaskite stock. Molybdenite, its oxidation product ferrimolybdite, pyrite, chalcopyrite, and limonitic ocher are associated with abundant quartz veins in the contact zone.

The region is arid, and the topography is of moderate relief.

The oxidized zone is 95 to 150 feet deep, and the bottom of oxidation parallels the surface drainage gradient. The water table lies below the lowest workings, which are 200 feet beneath the bottom of oxidation.

In the oxide zone 30 to 40 per cent of the total molybdenum is in the form of sulphide, whereas in the sulphide zone 87 per cent or more of the metal is present in that form. Total assay values, however, show no significant change in passing from one zone to the other.

Conditions at the Hall Property favored thorough oxidation, but molybenite oxidizes slowly, and the metal clearly does not migrate readily in any form. In comparison with other molybdenite deposits, oxidation of the Hall orebody has more than average relative importance.

The amount and depth of oxidation of molybdenite should be carefully considered in the examination of prospects, because no commercial process has been put in use to recover the metal from the oxide.

INTRODUCTION.

THE Hall Molybdenum Property is located in the Liberty Mining District about 25 miles north of Tonopah in Nye County, Nevada. The deposit is on the west slope of the arid and barren San Antonio Mountains at an elevation of 5,900 feet.

This paper presents a description and discussion of oxidation in the molybdenite orebody at the Hall Property in relation to the general geological setting and the various controlling factors. The distribution of molybdenum values is considered, and the occurrence of molybdenum as sulphide and as oxide.

The deposit has been explored to date by a total of 4,450 feet of shafts, drifts, and cross-cuts, and 354 feet of diamond drilling. The orebody has been extensively sampled. From 1935 to 1938 the U. S. Vanadium Corporation did about 3,500 feet of exploratory work, all from old Shaft No. 1

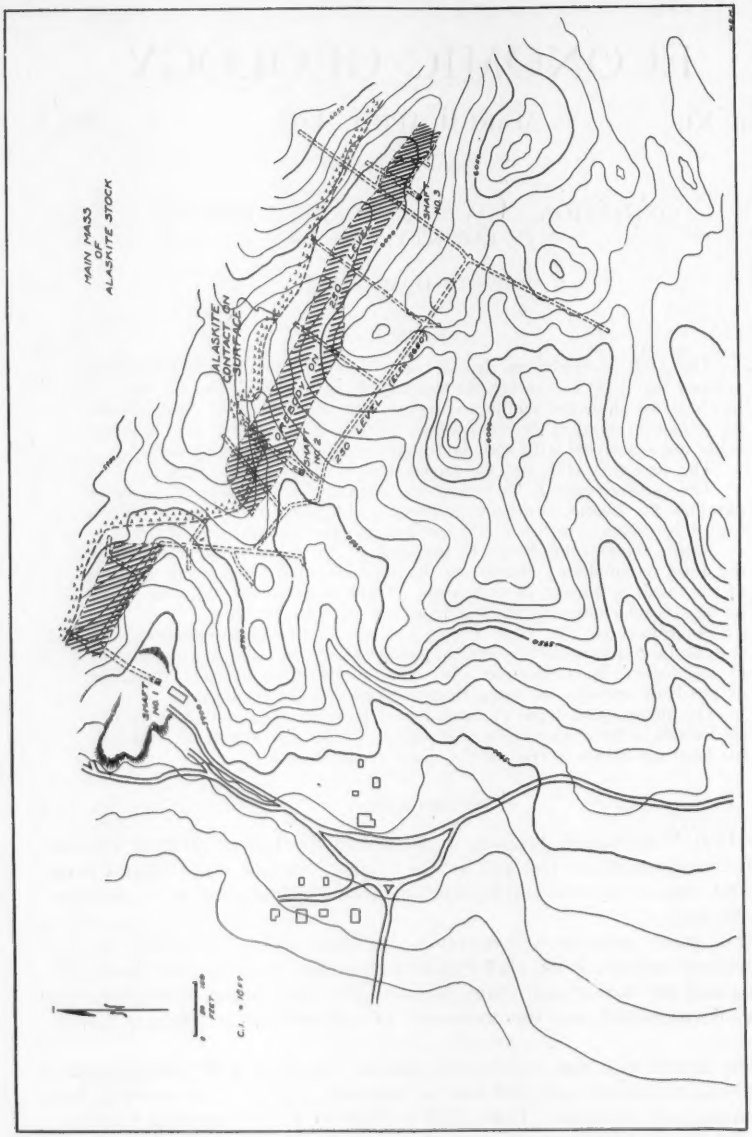


FIG. 1. General map of the Hall molybdenum deposit, showing surface topography, underground workings, outline of the ore body on the 250 Level, and alaskite-schist contact on the surface.

(Fig. 1), under the direction of Clarence H. Hall. The only data concerning oxidation secured during that period were in Shaft No. 1, which passes from oxidized to unoxidized material at a depth of 110 feet on a 70° incline. These workings were studied and sampled by the Freeport Sulphur Co. in 1940 and by the U. S. Bureau of Mines in 1942.

From June to November, 1943, Desert Silver, Inc., as agent for the Metals Reserve Company, carried on an exploration and sampling program. The writer, geologist for Desert Silver, Inc., acted as chief engineer in charge of operations, and the data presented here are based largely on the work done by that company.

ACKNOWLEDGMENTS.

For helpful discussion of the problems involved the writer wishes to express his thanks to Ira B. Joralemon, president of Desert Silver, Inc., Fred E. Gray, general manager, and Howard B. Nicholas, chief chemist; to Charles A. Anderson and M. W. Cox, of the U. S. Geological Survey; and to Clarence H. Hall, of the U. S. Vanadium Corporation.

GEOLOGY AND STRUCTURE.

General Geology.

The molybdenite deposit on the Hall Property as exposed to date stretches for about 1,200 feet northwest-southeast along the southern margin of a roughly circular alaskite stock. The stock has an average diameter at the surface of 2,500 feet.

The alaskite has been intruded into highly metamorphosed, contorted, and faulted schist of varying character. The alaskite-schist contact is irregular both in plan and section. In the area explored by the workings the contact has an average dip of about 80° NE, but it varies locally as the result of offsets by flat faults and by original intrusive irregularities, especially in the eastern part of the body (see Fig. 4). The strike of the schistosity is parallel to the alaskite contact, but the dip is somewhat less steep, being on the average about 70° NE.

The contact is characterized both in the alaskite and in the schist by very extensive silicification and by a great abundance of quartz veins. The quartzose character of the rocks diminishes progressively in both directions from the contact, which, because of the extremely high proportion of quartz, can be defined only approximately within a zone 10 to 15 feet or more in width.

The contact zone, which is the locus of molybdenum deposition, shows the results of strong shearing stresses. The alaskite in that area contains close-spaced shear planes and large quantities of fault gouge. The schist near the contact reveals a distinctly greater degree of foliation, kaolinization, and gouge formation than it does at a distance from the alaskite.

Andesite dikes, ranging in width from a foot or two up to 70 feet at one place on the 250 Level, have been intruded into the schist near the alaskite

FIG. 1. General map of the Hall molybdenum deposit, showing surface topography, underground workings, outline of the ore body on the 250 Level, and alaskite-schist contact on the surface.

contact. These dikes, which have been much disturbed and offset by faults, apparently strike nearly parallel to the contact, and are vertical or dip steeply northeast. Flat faults, dipping 20° to 45° SW, have offset these dikes and the alaskite-schist contact (see Figs. 3 and 4). Extensive faulting has also taken place throughout the contact zone parallel to the foliation of the schist.

A vertical north-south fault cuts the orebody and the contact about 225 feet east of Shaft No. 1. This fault has displaced the contact and the westernmost 225 feet of the orebody on the 250 Level approximately 125 feet to the north.

The Orebody.

The molybdenum-bearing orebody between the lowest workings (250 Level) and the surface has an average width of 53 feet. On the 250 Level the average width is 75 feet (see Fig. 1), but the exploratory work has shown that the body becomes progressively narrower upward to a width of about 30 feet at the surface. It contains numerous dike segments between the 250 Level and the surface. The dikes are so much disrupted by faulting that they cannot be predicted for any appreciable distance ahead of development. The dikes are everywhere barren, or show only traces of molybdenum. One andesite mass, a nearly continuous dike, outcrops on the surface and also forms the footwall of a large portion of the orebody on the 250 Level. The footwall elsewhere is an assay boundary in schist. Alaskite forms the hangingwall, although in a few places values are found for several feet within the alaskite.

Molybdenite and its oxidation product are found principally in the abundant quartz veins and lenses concentrated in the contact zone. The molybdenite, which is generally very fine-grained, is in small flakes and bunches in fractures in the quartz. Some molybdenite has formed as thin coatings directly on the foliation planes of the schist, and some lies along the borders of gouge-filled shear planes.

Most of the molybdenum values which can be considered commercial are in the schist, but, as stated above, the mineralization has penetrated a few feet into the alaskite hangingwall in several places.

Associated with the molybdenite in the sulphide zone are pyrite and chalcopyrite. Pyrite is the most abundant sulphide in the deposit. The oxidized portion of the orebody contains abundant ocherous limonite, some ferrimolybdite ($Fe_2O_3 \cdot 3MoO_3 \cdot 7\frac{1}{2}\ H_2O$),[1] residual pyrite, and a little residual molybdenite. Relatively small amounts of limonite, and also presumably some ferrimolybdite, have been deposited on certain fractures within the sulphide zone. A few bunches of malachite and azurite were seen below the general level of oxidation.

A blue amorphous mineral was found at one place on the surface on the Hall Property. This may possibly be the mineral ilsemannite, formed under

[1] Schaller, W. T.: The chemical composition of molybdic ocher. Am. Jour. Sci., 4th ser., 23: 297–303, 1907; Guild, F. N.: The composition of molybdite from Arizona. Am. Jour. Sci., 4th ser., 23: 455–456, 1907; Dana, E. S.: A Textbook of Mineralogy, 4th ed., p. 774, 1932.

unusual conditions indirectly from molybdenite. Hess [2] considered the mineral to be an oxide, although earlier work [3] reported it to be a hydrous sulphate of molybdenum. Since ilsemannite is soluble in water, it is found only where very arid conditions prevail. Its preservation, for some little time at least, would be possible under the climatic conditions at the Hall Property.

Character of the Country Rock.

The main mass of alaskite consists of medium-grained massive rock made up principally of pink orthoclase, white quartz, and muscovite. The texture is porphyritic in some places, with quartz phenocrysts up to one-half inch in diameter. At and near the contact with the schist the alaskite is highly silicified, and it is chalky white in the contact zone except where it is stained by limonite. Here the feldspar has been largely kaolinized and replaced by quartz and sericite; quartz veins are numerous; and strong shearing has caused the formation of much fault gouge.

The schist exhibits many different facies, which are complexly intermingled as the result of faulting and folding. There are exposures of fine-grained, blocky, calcareous rock; of hard, gray, even-textured slate; of quartzitic schist; and of fissile, pyritic, mica-schist. In the orebody along the alaskite contact most of the schist is strongly foliated, sericitic, fine-grained, and highly silicified. It contains isolated grains, nodules, and lenses of pyrite. Veins and pods of milky quartz are numerous. Gouge-filled fault fractures, most of them parallel to the schistosity, are prominent features. In the oxide zone the schist has been greatly stained by yellowish-brown limonite, but in the sulphide zone it is gray or greenish.

The andesite dikes consist of blue-gray, dense, blocky, even-textured rock. Portions of the dikes have been softened by kaolinitic alteration.

TOPOGRAPHY AND CLIMATE.

A dry wash follows the sheared alaskite-schist contact northwestward along the outcrop of the main portion of the orebody. Just east of the north-south fault the alaskite margin bends southward, and the gully turns with it, thence cutting southwest for 600 feet diagonally through the schist footwall to the alluvial slopes at the margin of the range. Another dry wash parallels the contact along the 225 feet of known ore west of the north-south fault (see Fig. 1). Shaft No. 1 is located in this wash. The washes are filled with gravel to a depth of 10 to 15 feet. The floor of the eastern gully averages about 40 feet in width. The wash at Shaft No. 1, at the edge of the alluvial slope, is 80 feet wide.

From the east end of the developed orebody to the north-south fault the dry wash descends from an elevation of 6,010 feet to 5,940 feet in a distance of 800 feet, or with a gradient of 8.75 per cent.

[2] Hess, F. L.: Molybdenum deposits—a short review. U.S.G.S., Bull. 761, p. 7, 1924.
[3] Schaller, W. T.: Ilsemannite, hydrous sulphate of molybdenum. Jour. Wash. Acad. Sci. 7: 417–420, 1917; Hess, F. L.: Ilsemannite at Ouray, Utah. U.S.G.S., Bull. 750-A, pp. 1–16, 1923.

On either side of the dry washes the hill slopes rise steeply. They show numerous bare rock outcrops and a thin veneer of talus. In the alaskite directly north of the washes the hills reach heights of about 100 feet above the gully floor. Successively higher alaskite hills extend northeast of the orebody for 2,600 feet to a high point of 6,520 feet elevation within the alaskite stock. In the schist the ridges adjacent to the dry washes on the south are about 60 feet above the floor.

The present climate in the region is arid. Average annual rainfall is about 5.5 inches.[4] Rarely as much as 1 inch or 2 inches may fall in any one month. Although cloudbursts occur at times in the Tonopah area, the San Antonio Range is not generally subject to them, and there is no evidence of cloudburst activity in the vicinity of the Hall Molybdenum Property. The small dry washes along the molybdenum orebody drain only a small area at the margin of the San Antonio Range, and would never carry a very large proportion of the total run-off.

Scattered stunted sagebrush is practically the only vegetation in the entire area.

OXIDATION.

General Character of Oxidized and Unoxidized Material.

The oxidized material within the ore zone and beyond its limits, and in both schist and alaskite, is characterized by abundant yellowish-brown limonitic ocher containing some intimately associated ferrimolybdite. The ocher fills cracks in the rock and stains the surface extensively.

Blanchard and Boswell[5] describe characteristic forms of limonite derived from the oxidation of molybdenite. In the deposit in question, however, any limonite of molybdenite derivation has been obscured by the excessive amount of limonite derived from pyrite. The abundant limonite so derived has remained in place because of the climatic and erosional history and because of the effect of neutralizers in the country rock, as will be discussed later. It is to be remembered also that the amount of original molybdenite in the deposit was very small, especially in proportion to pyrite.

The unoxidized rocks have already been described. In the schist the color contrast between the yellowish-brown of the oxidized rock and the gray of the unoxidized material is striking and distinctive.

Surface of Bottom of Oxidation.

The contact between oxidized and unoxidized material is nearly everywhere sharp, although highly irregular in detail. In some places the yellowish-brown material passes into gray unoxidized schist within a few inches. Because of the extension of oxidation along fractiures into the sulphide zone,

[4] Meinzer, O. E.: Geology and water resources of Big Smoky, Clayton, and Alkali Springs Valleys, Nevada. U.S.G.S., W.S.P. 423, pp. 65–67, 1917.

[5] Blanchard, R., and Boswell, P. F.: "Limonite" of molybdenite derivation. Econ. Geol. 30: 313–319, 1935.

there is a zone several feet in thickness which contains both types of material, but the demarcation of the two types is distinct.

The prospect shafts and diamond drilling suggest that the surface at the bottom of the oxide zone is of gentle relief, and over the orebody it rises upward to the east with a gradient of approximately 9 per cent. This is closely parallel to the gradient of the floor of the dry wash, which rises eastward at the rate of 8.75 per cent (see Fig. 2).

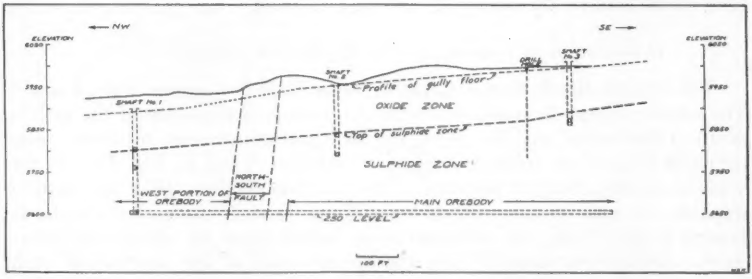


FIG. 2. Longitudinal vertical projection of the Hall molybdenum orebody, showing the oxide and sulphide zones and their relation to the surface drainage gradient. The water table is at some distance below the 250 Level, which represents the greatest depth of exploration.

The low relief of the bottom of oxidation is in contrast with the overlying surface topography, with its rather steep slopes on either side of the gullies. The bottom of oxidation clearly does not reflect the details of the present topography, although it parallels closely the general drainage slope. This is a typical relationship.[6]

The bottom of the oxide zone in the orebody is on the average 100 feet below the floor of the dry wash. Beneath the hills which rise directly from the floor of the gully, the bottom of oxidation is much deeper: in Drill Hole No. 1, near the east end of the orebody, the bottom of oxidation is 150 feet below the hillside at a distance of only 100 feet horizontally from the center of the dry wash.

Relation of Oxidation to Structure.

It is apparent that the highly sheared, faulted, and nearly vertical contact zone along which the molybdenum has been concentrated was also particularly favorable to the action of downward-moving oxidizing solutions. The abundant steep faulting along shear planes in the schist likewise provided good channelways for surface waters.

The steeply dipping dikes in the contact area furnished channelways on their upper surfaces at least, but in some cases they protected from oxidation

[6] Schneiderhöhn, H.: Oxydations- und Zementationszone der sulfidischen Erzlagerstätten. Forts. Min. Krist. Petr. 9: 86, 1924.

the rock beneath. This is well shown in Shaft No. 3 (Fig. 4), where the sulphide zone extends abnormally high against the lower surface of the dike.

The local irregularities in the bottom of oxidation can be explained by these various structural features, which either made possible deeper than average oxidation, as in the case of steep faults, fractures, and planes of schistosity; or else kept oxidation at a higher than average elevation, as in the case of the under surfaces of impervious dikes. The minor irregularities are insignificant in relation to the general attitude of the bottom surface of oxidation, which follows the overlying drainage gradient.

Distribution of Values between Oxide and Sulphide Zones.

The vertical distribution of values in the orebody is shown in Figs. 3 and 4. The notable feature in connection with the process of oxidation of the molybdenite is the lack of any change in total molybdenum content in passing from the oxide zone to the sulphide zone (note samples A and B, Fig. 3). In the oxide zone only 30 to 40 per cent of the total molybdenum is in the form of sulphide, whereas in the sulphide zone 87 per cent or more of the metal is present in that form; but the total assay values show no significant differences. Within the sulphide zone the orebody east of the north-south fault has an average grade of 0.34 per cent MoS_2 per ton, total value, with no important lateral variation. The portions of the same body explored in the oxide zone have approximately the same average total molybdenum content. (Sample C, Fig. 3, for example, shows 0.34 per cent MoS_2 per ton, and is nearly 100 per cent oxidized.) All assays were made on large muck samples to avoid the effect of local concentrations of values.[7]

General Discussion of Oxidation.

The results of oxidizing action observed at present in the Hall Molybdenum orebody have been produced under the influence of many correlated factors: climate and precipitation, past and present; topography; rock structure; chemical, mineralogical, and physical character of the ore and wall rocks; and geologic history.

In regions of arid climate, where the water table is deep, oxidation can be expected to greater depths than in humid regions.[8] On the Hall Property oxidation is relatively deep, but the present water table is far deeper. For example, no ground water was encountered in the lowest working on the 250 Level some 200 feet below the average bottom of oxidation. Evidently arid conditions have been on the increase in recent geological time, so that the water table has been falling progressively lower, and has kept ahead of oxidation and erosion. There is evidence, indeed, of increasing desiccation throughout Pleistocene and Recent times in the Great Basin as a whole.[9]

[7] Assays and oxide determinations were made by Howard B. Nicholas, Chief Chemist for Desert Silver, Inc.

[8] Schneiderhöhn, H.: op. cit., pp. 75, 87; Lindgren, W.: Mineral Deposits, 4th ed., p. 814, 1933.

[9] Knox, H. H.: An effect of climatic change on the superficial alteration of ore deposits. ECON. GEOL. 17: 660, 1922.

FIG. 3.

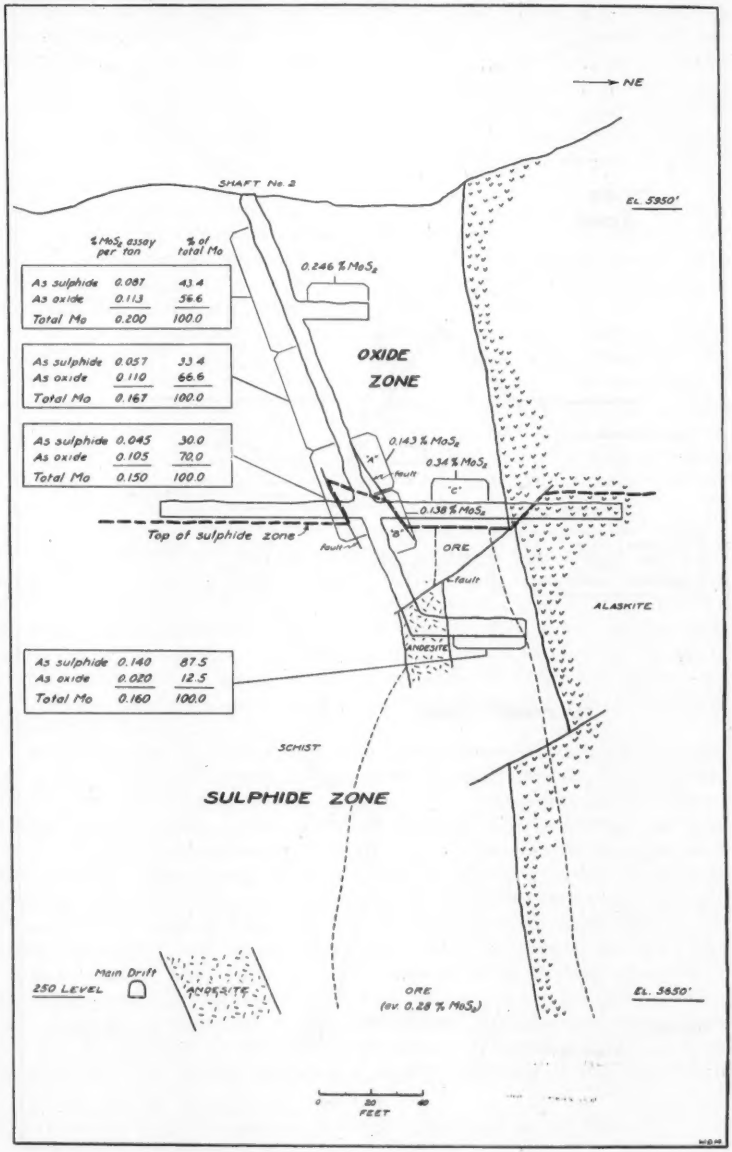


FIG. 3. Section through Shaft No. 2, Hall Molybdenum Property, showing molybdenum values in the oxide and sulphide zones.

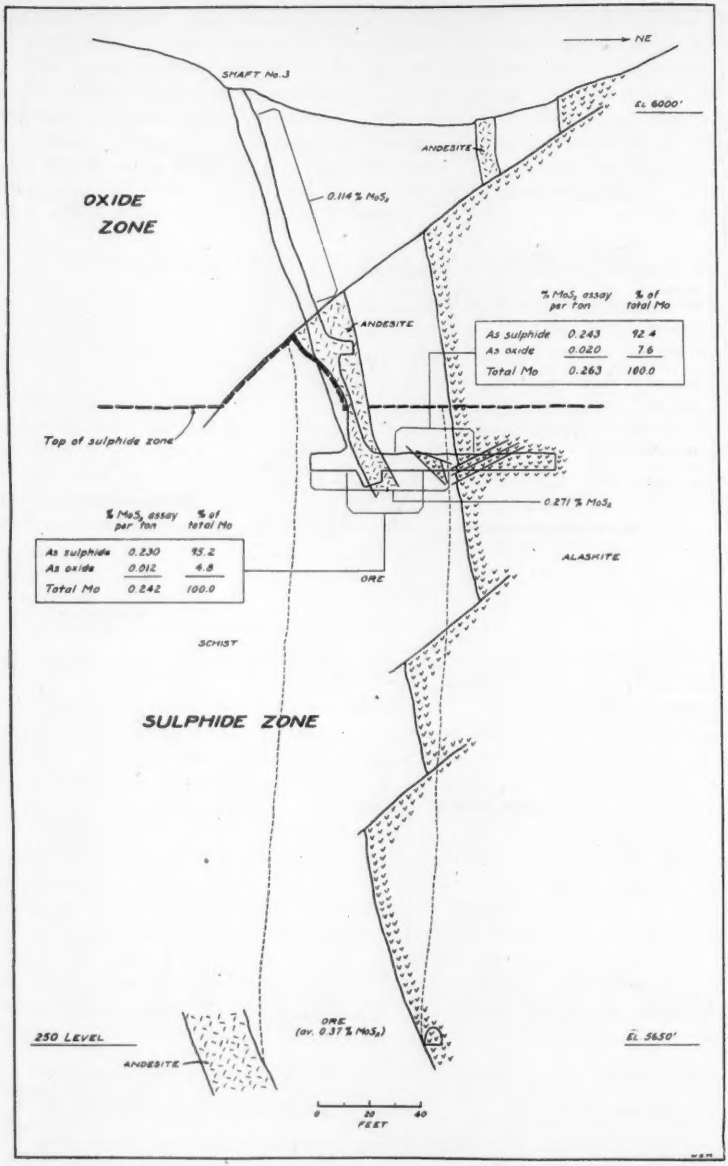


FIG. 4. Section through Shaft No. 3, Hall Molybdenum Property, showing molybdenum values in the oxide and sulphide zones.

The climate was probably arid during the entire Quaternary period, but there was at least one humid interval, as shown by the existence in the valleys adjacent to the Hall Property of Pleistocene lakes with large surfaces of evaporation.[10] The humidity at that time was only relative, however, and at no time can the climate be said to have been of a different order from what it is now. Fenneman [11] points out that, as far back as we can see in the current erosion cycle, the climate was about the same as at present in the Great Basin.

Oxidation has been aided also by the character of the local precipitation. The freedom from cloudbursts has allowed the surface waters, slight as they are, to work on the deposit rather than all run off in catastrophic floods. The relatively even distribution of rainfall, without marked seasonal differences, is helpful to the process of steady and continued oxidation.[12]

The topography of the San Antonio range in general is characteristic of maturity in desert regions. This stage of the erosion cycle is most favorable to the development and preservation of an oxide zone. The movement of surface waters is not too fast in relation to the process of weathering; a stable water table exists; sulphides are oxidized, but the metals are re-precipitated as acid salts in the oxide zone, and are not leached out. Youth and extreme relief, with rapidly moving surface waters and great speed of erosion, would be unfavorable for maximum development of an oxide zone.[13]

The chemical character of the country rock in the deposit has aided in preventing removal and migration of the oxidation products of pyrite and molybdenite. Feldspar in the alaskite, some calcite associated with quartz in the veins, and the calcareous nature of certain horizons in the schist have evidently served as neutralizers for the acidic waters which resulted from oxidation of the relatively large amount of pyrite. This chemical factor, together with the other factors described, accounts for the re-precipitation and retention in the oxide zone of the two principal metals in the form of limonite and ferrimolybdite.

It has already been pointed out that the extensive fracturing and faulting along the contact zone, which is the locus of the Hall orebody, have furthered the oxidation process by locally increasing the permeability of the rocks to surface water. Without the effects of shearing and fracturing, the rocks would be relatively impermeable, because there is little soluble material in the chemical and mineralogical makeup of the alaskite and schist. Clearly, the physical zone of weakness provided by the sheared contact was not only favorable as a locus of deposition for ore minerals from rising thermal solutions, but also served subsequently as a useful channelway for descending surface waters. The oxidizing solutions have followed those channelways, but in the insoluble and impermeable rock adjacent to the fractures oxidation has been less complete, and some islands of unoxidized material remain there.

The concurrence of the factors mentioned as favoring oxidation would have caused even deeper and more complete oxidation of the Hall Molyb-

[10] Meinzer, O. E.: op. cit., p. 64.
[11] Fenneman, N. M.: Physiography of Western United States, p. 361, 1931.
[12] Schneiderhöhn, H.: op. cit., p. 76.
[13] Ibid., pp. 78–79.

denum orebody than we see today if the contact zone had been longer exposed to the weathering process. It is true that neither the age of mineralization nor of the alaskite intrusion can be accurately determined, largely because the Tertiary volcanics exposed in the San Antonio range south of the deposit have been removed from the area under discussion. The medium- to coarse-grained alaskite was certainly intruded under considerable cover, however, so that the contact zone must have been for a long time deeply buried. We can probably assume that the molybdenum deposit was exposed to the oxidizing action of surface waters only during Quaternary and Recent times, after the Tertiary cover had been removed by erosion.

Meinzer [14] shows that the mountains and valleys were essentially the same as now by the beginning of the Quaternary. During that period erosion and the formation of detrital fill were the active processes, and oxidation of the ore deposit could begin.

The oxidation of the Hall deposit, therefore, probably took place entirely under topographic and climatic conditions generally similar to the present, the principal change during its history being a gradually increasing aridity and a slow lowering of the water table. Oxidation, although favored by structure and topography, did not proceed with sufficient speed to keep up with the dropping of the water table, and erosion was not rapid enough to remove the oxidized material.

Oxidation of the Molybdenite.

The distribution of values in the deposit shows clearly that no significant migration of molybdenum has taken place as the result of oxidizing action, and, although conditions were generally favorable for it, no zone of secondary enrichment was formed.

Apparently molybdenite is oxidized to MoO_3, which combines with ferric oxide from the oxidation of pyrite to form ferrimolybdite.[15] This compound is only slightly soluble under near-surface conditions. Molybdenum in the oxide form would therefore not be easily moved and concentrated.

Molybdenite itself is not readily oxidized. It is not attacked by H_2SO_4, by HCl, or even by ferric sulphate.[16] The slow oxidation of molybdenite, its lack of mobility, and the fact that enough molybdenum cannot be taken into solution to form secondary enrichment zones, have been noted in various instances.[17]

In the Hall Molybdenum deposit, and in most other occurrences, pyrite is intimately associated with molybdenite. Gottschalk and Buehler,[18] in their experiments on the protective action of certain sulphides upon other sulphides,

[14] Meinzer, O. E.: op. cit., p. 64.

[15] Butler, B. S., and Vanderwilt, J. W.: The Climax molybdenum deposit, Colorado. U.S.G.S., Bull. 846-C, p. 232, 1933; Horton, F. W.: Molybdenum: its ores and their concentration. U.S.B.M., Bull. 111, p. 11, 1916.

[16] Lindgren, W.: op. cit., pp. 821, 874.

[17] Krusch, P.: Die Einteilung der Erze mit besondere Berücksichtigung der Leiterze sekundärer und primärer Teufen. Zeits. f. prakt. Geol. 15: 137, 1907; Ball, S. H.: Molybdenite and its occurrences. E.M.J. 104: 334, 1917; Butler and Vanderwilt: op. cit., 1933, p. 232.

[18] Gottschalk and Buehler: Oxidation of sulphides: second paper. Econ. Geol. 7: 31, 1912.

found molybdenite to be above pyrite in the electro-motive series. Hence pyrite, if moistened and in contact with molybdenite, should protect molybdenite from oxidation and at the same time have its own oxidation accelerated. (It is to be noted that this is not the usual result of the presence of pyrite, which has an accelerating effect in contact with most of the other common sulphides.) [19] The possible protective action of pyrite may be an additional reason, besides the fundamental resistance of the molybdenite itself, for the slow oxidation and low mobility of molybdenite, even under nearly optimum conditions. In the Hall deposit oxidation in general was thorough, and it had favorable opportunity to act, yet even in such low-grade material some molybdenite is visible in the oxide zone, and assays show that 30 to 40 per cent of the total molybdenum in the oxide zone is still present as sulphide. Pyrite, on the other hand, has been almost completely oxidized.

Comparison with Oxidation in Other Molybdenite Deposits.

In most molybdenite deposits of commercial value which have been described to date, the effect of oxidation has apparently not been of sufficient importance to invite much attention.

At Climax, Colorado, the oxidation as a whole has been shallow and incomplete.[20] On relatively open fissures, ferrimolybdite goes to considerable depth, but in such cases it is not of economic importance. As in the Hall deposit, there is no evidence of enrichment or of significant transportation of molybdenum.

The oxidized material at Climax is similar in character to that at the Hall Property. Yellow or reddish limonite is a universal stain over the mineralized area, and with it, mostly within a few feet of the surface, is ferrimolybdite. While the near-surface portions of the Climax orebody were being mined, it was found that generally 10 to 20 per cent of the total molybdenum content of the ore was contained in the oxide and consequently was lost in flotation.[21] Oxidation at Climax was in general less complete than in the Hall deposit, where 60 to 70 per cent of the total molybdenum in the zone of oxidation is in the form of oxide. In a few places, however, more highly oxidized material could be found at Climax. For example, the analysis of ore used in tests for the recovery of ferrimolybdite showed 78 per cent of the total molybdenum in the oxide form: [22]

Insol	94.5 %
MoS_2	.223
MoO_3	.697
CaO	Tr.
Fe	2.91
P	Tr.

[19] Buehler and Gottschalk: Oxidation of sulphides. Econ. Geol. 5: 29, 1910; Carmichael, F.: Catalytic action in the oxidation of sulphides and arsenides. Toronto Univ. Studies, Geol. ser., no. 24, pp. 47–53, 1927.

[20] Butler and Vanderwilt: op. cit., pp. 229–231; Coulter, W. J.: Mining molybdenum ore at Climax, Colorado. E.M.J. 127: 396, 1929.

[21] Haley, D. F.: Molybdenite operations at Climax, Colo. Trans. A.I.M.E. 61: 71–76, 1919; Eardley-Wilmot, V. L.: Molybdenum. Can. Dept. Mines, Mines Br., publ. 592, p. 224, 1925.

[22] Doerner, H. A.: Recovery of molybdite from the ore. U.S.B.M., T.P. 399, pp. 10–12, 1926.

The probable reasons for the shallow and incomplete oxidation at Climax are the low temperature, which, by freezing, has prevented the free downward movement of surface solutions during glacial and post-glacial times; and the removal by glaciation of much of the oxidized material which may have been formed in the more favorable pre-glacial climate.

The contrast in climatic conditions at Climax and at the Hall Property, together with the presence in the latter of structural features peculiarly favoring oxidation, appears to account for the greater relative importance of oxidation in the Hall deposit.

At Sweetwater, Nevada,[23] a molybdenite deposit outcrops on the surface for 3,000 feet along a vertical dike of decomposed granite. Molybdenite and ferrimolybdite are disseminated in flakes, seams, and pockets. Oxidation to ferimolybdite probably extends to "considerable depth," but not enough work has been done to ascertain this.

One sample showed 3.62 per cent MoS_2 and 6.78 per cent MoO_3, or 70 per cent of the total molybdenum as oxide. Another sample, used for recovery tests, gave the following analysis:

Insol	92.80 %
MoS_2	1.08
MoO_3	.63
CaO	1.00
Fe	.87
P	.017

In this sample, only 39 per cent of the total molybdenum is in the form of oxide.

At Sweetwater, climatic and probably also structural conditions are more nearly like those at the Hall property than at Climax.

At the Questa molybdenite deposit (formerly the R. & S. Mine) in New Mexico[24] ore averaging 2 per cent MoS_2 per ton is in veins in a shear zone in alaskite. "Erosion in the region has been so rapid that the oxidized mantle at the outcrop of the veins is very thin, varying in thickness from a few inches to a maximum of a few feet. The only oxidation minerals observed were molybdic ocher . . . resulting from the alteration of molybdenite, and small amounts of limonite derived from pyrite."[25] Vanderwilt also mentions the rapid oxidation and erosion evidenced in the deposit as a whole, but he points to the presence of considerable molybdenite at the surface as an example of the relative resistance of that sulphide to attack by oxidizing solutions.

Removal by rapid erosion of the oxidized material from a molybdenite deposit is also reported by Schrader[26] at Rocky Bar, Idaho. This is in contrast to the relatively slow erosion of the Hall deposit.

As at the Hall Molybdenum Property, insignificant migration of molybdenum values under oxidizing conditions has been noted in a Russian deposit

[23] Doerner, H. A.: op. cit., pp. 2–3.

[24] Larsen, E. S., and Ross, C. S.: The R. & S. Molybdenum Mine, Taos County, N. M. Econ. Geol. 15: 567–573, 1920; Vanderwilt, J. W.: Geology of the "Questa" Molybdenite Deposit, Taos Co., N. M. Colo. Sci. Soc. Proc. 13: no. 11, 599–643, 1938.

[25] Larsen and Ross: op. cit., p. 572.

[26] Schrader, F. C.: Molybdenite at Rocky Bar, Idaho. U.S.G.S., Bull. 750-F, pp. 87–99, 1924.

described by Shibakov:[27] "Molybdenum occurs as molybdenite associated with quartz as a secondary constituent of the porphyry ores. Molybdenum occurs in the oxidized zone as a yellowish-green ocher. The molybdenum content decreases from the periphery of the porphyry inward, but no change in content is observed in a downward direction, in the oxidized zone as well as in the unoxidized zone. . . ."

Economic Considerations Regarding Oxidation.

Although in most molybdenite deposits the relative amount of molybdenum in the oxide form is not great, at the Hall Property the depth and thoroughness of oxidation is significant, and since no suitable economic method of treatment of oxidized material has been devised, recovery of a large proportion of the molybdenum in that deposit could not be made.

Experiments have been performed with the object of developing a method of recovering molybdenum commercially from ferrimolybdite, especially at Climax, but the methods have not been put into use. In the earlier history of mining at Climax, when oxidized material was in important quantity, the recovery problem was actively studied,[28] but no process was put in operation. Leaching methods were found to be feasible,[29] but in recent years the content of ferrimolybdite has been too low at Climax and elsewhere to make such operations profitable.[30]

The fact remains, however, that in some low-grade molybdenite deposits oxidation may be of sufficient importance to condemn the property. For this reason, careful study and analysis of the depth and amount of oxidation and of factors influencing the process are essential in the testing of any molybdenite prospect.

SUMMARY AND CONCLUSIONS.

1. The Hall Molybdenum deposit near Tonopah, Nevada, has been developed for 1,200 feet in length and 30 to 75 feet in width in schist along the southern margin of an alaskite stock. Molybdenite, its oxidation product ferrimolybdite, pyrite, chalcopyrite, and limonitic ocher are found in and associated with abundant quartz veins in the highly sheared contact zone.

2. Dry gullies follow most of the contact zone. The region is one of moderately high relief, and has very little vegetation. Rainfall averages about 5.5 inches annually.

3. The oxidized zone in the ore deposit is 95 to 150 feet deep. It is characterized by very abundant yellowish-brown limonite and small amounts of associated ferrimolybdite. The bottom of the zone of oxidation follows the general drainage gradient.

[27] Shibakov, M.: On molybdenum and copper-porphyry ores of Kounrad. Redkie Metally 5 (3): 16–23, June, 1936—Russian; quote from abstract in Annot. Bibl. Econ. Geol., 1936, vol. 9, no. 2, title 416, July, 1937.

[28] Doerner, H. A.: Recovery of molybdite from the ore. U.S.B.M., T.P. 399, 13 pp., 1926; Hess, F. L.: Molybdenum deposits—a short review. U.S.G.S., Bull 761, 1924.

[29] Petar, A. V.: Molybdenum. U.S.B.M., Econ. Paper 15, pp. 13–14, 1932.

[30] Duggan, E. J.: Climax milling practice. A.I.M.E., Trans. 153: 588, 1943.

4. In the oxide zone 30 to 40 per cent of the total molybdenum is in the form of sulphide, whereas in the sulphide zone 87 per cent or more of the metal is present in that form. However, migration of molybdenum has been insignificant, because total assay values show no appreciable change in passing from the oxide to the sulphide zone. Total average grade in both zones is about 0.34 per cent MoS_2 per ton in the orebody.

5. Arid climate throughout the current erosion cycle, relatively even distribution of rainfall, mature topography during the period of exposure to weathering, extensive fracturing of the contact zone, and the presence of neutralizers in the country rock favored the thorough development and preservation of the oxidized zone.

6. The concurrence of favorable factors would have caused even deeper oxidation than we now see, but the deposit was probably exposed to oxidation only during Quaternary and Recent times, after the removal of a thick cover of Tertiary volcanics.

7. Molybdenite oxidizes very slowly, even under favorable conditions such as existed at the Hall Property, and molybdenum clearly does not migrate readily in any form. In addition, pyrite, which has been almost completely oxidized in the upper zone at the Hall Property, may have had a protective effect on molybdenite.

8. In most known molybdenite deposits oxidation is relatively shallow and incomplete. For this reason no commercial process for the recovery of molybdenum from the oxide has been thoroughly developed and put into operation. In any molybdenite prospect a careful analysis of the depth and thoroughness of oxidation should be made because, as in the case in question, it might be sufficient to exclude the possibility of commercial operation.

MAGMA COPPER COMPANY,
SUPERIOR, ARIZONA,
August 19, 1944.

GEOLOGY OF THE ROPES GOLD MINE, MARQUETTE COUNTY, MICHIGAN.[1]

T. M. BRODERICK.[2]

ABSTRACT.

The Ropes Mine, situated three and one-half miles northwest of Ishpeming, Michigan, was operated from 1883 until 1897 and produced $647,902.37 gold and silver. Recovery of $54,929.38 from some of the old tailings brings the total to $702,831.75.

The ore mined occurred in nearly vertical quartz lenses cutting diagonally across a vertical tabular body of Keewatin lavas and volcanic fragmentals separating two bodies of Laurentian peridotite. The Keewatin and immediately adjacent peridotite are strongly sheared, the former being chloritized and the latter serpentinized and steatitized. In the vicinity of the quartz lenses the Keewatin is silicified, sericitized and pyritized. The mineralization is probably of post-Middle Huronian age.

The quartz veins carry tetrahedrite, pyrite, chalcopyrite and minor amounts of other sulphides, and the ore milled ran about .2 oz. gold and .9 oz. silver per ton, of which nearly one-third was lost in the tailings.

Recent explorations have shown another type of ore occurring as a pyritic dissemination in schist adjacent to the quartz veins. There is about eight times as much ore of this type averaging .13 oz. gold and .7 oz. silver as there was in the quartz vein nuclei.

The old mine was over 800 feet deep and recent diamond drilling from the bottom level has shown the persistence of favorable rock alteration and gold values for hundreds of feet below that elevation.

INTRODUCTION.

THE Ropes Gold Mine is located in Section 29, T48N–R27W, Marquette County, Michigan, about three and one-half miles northwest of Ishpeming. A good highway runs to the property and in recent years a branch of the Chicago North Western Railway terminated within a quarter mile of the old Ropes shaft. The gold deposit outcrops on the south side of an east-west valley which marks a shear zone. Hills of peridotite rise on each side of the valley. A small creek runs eastward into Deer Lake, which has been backed up as a reservoir, to within a quarter of a mile east of the old shaft.

The writer's first connection with the gold deposits of Michigan was in the early part of 1933 when he started review of the literature preliminary to visits to the properties themselves. These first visits were made chiefly in connection with the duties of a position which he then held as Research Professor of Geology at the Michigan College of Mining and Technology. Among the old mines and prospects seen were the Ropes, Michigan, Superior, Fire Center, Holyoke, Ten Kilns, and others known in the earlier days. The reported placer gold of the Yellow Dog River was also investigated. It

[1] Presented before the Society of Economic Geologists, December 1939, at Minneapolis, Minnesota.

[2] Chief Geologist, Calumet and Hecla Consolidated Copper Company.

seemed that there were sufficiently favorable conditions present in the district to warrant more thorough explorations than were being made. Accordingly, in 1934 the Calumet and Hecla Consolidated Copper Company took over the leases covering the old Ropes and surrounding property.

The new information obtained through the association with these investigations of the College and later those of Calumet and Hecla forms the basis of this preliminary report. It has been delayed this long because it was hoped that active mining would be started at the Ropes, and a further opportunity would thereby be afforded to study some of the more obscure geological characteristics of the deposit. However, in view of the uncertainty of mining being started soon, it seems best to record the principal features of the geology of the ore body as known at this time.

Besides acknowledging indebtedness to Calumet and Hecla and the Michigan College of Mining and Technology for the opportunity to study the area, the writer wishes to thank Dr. C. O. Swanson, Mr. C. D. Hohl and Mr. H. N. Eidemiller, who assisted in the geological work. The officials of the Michigan Gold Mining Company were always most cordial in allowing access to their property, and the publishers of "The Ishpeming Iron Ore" freely granted the use of their files covering the early period when there was active mining and exploration in the district. The annual publications of the State of Michigan, known as "Mineral Resources" and "Mineral Statistics," are valuable sources of information concerning the early period of interest in Michigan gold.

HISTORY.

The first record of gold being found in Michigan goes back to the days of Douglass Houghton, the first state geologist (1837–1845), who on one occasion was camped somewhere between L'Anse and Marquette, no one knows exactly where. According to the story, on his return from a short trip from camp, he displayed some coarse gold which he had found in a little stream. Before he could follow up his discovery he died, without leaving a record of the place, but it was generally believed that he found the gold somewhere in the mineralized area north of Ishpeming.

In January, 1864, certain specimens of a quartz vein from the Holyoke silver mine in Section 2, T48N–R27W, were found to contain considerable gold.

In the late seventies, Julius Ropes of Ishpeming spent some time examining the asbestos veins and serpentine marbles north of town, and in 1880 he found a gold bearing stringer of quartz on the north side of a valley in Section 29, T48N–R27W. He later found the mineralization some hundreds of feet west on the south side of the valley where conditions were favorable for mining. In October, 1882, mining started, and in 1883 a 5 stamp mill was erected and ran about two months, treating about 200 tons of ore, which yielded $10.00 per ton. Work was resumed in April, 1884, and a 25 stamp mill was put in operation in November, 1884. Regular operations then were carried on until the mine was shut down by the creditors in July 1897. The mine thus ran for a fifteen year period, which ended thirteen years before the

Porcupine Camp of Ontario hit its stride, and sixteen years before the Kirkland Lake district got under way.

The history of the Ropes mine was one of continual discouragement. The ore was low grade, the tailings loss rather high, the gangue had considerable talc, which clogged the stamps and screens and otherwise interfered with milling, and there were never enough funds on hand to equip and open the mine in advance of stoping. On the other hand, the following advantages were urged at the time of the shut-down: the location was favorable, the proportion of the ore-bearing formation explored was small, railway was nearby and water abundant, the mine was dry and the openings stood without timbering.

After the shut-down in 1897, the water was allowed to rise. In 1898, an option was taken on the property by Detroit people, who were to spend several thousand dollars in opening up some new ore shoots said to exist in the upper parts of the mine. Results were not encouraging, and in December they decided to pump out the water which had risen up about half way by that time, and examine the lower workings. Finally, after some exploratory work and sampling, the option was given up in May, 1899.

The mine was offered in a receiver's sale in 1899, but the first sale was set aside by the court because the bids were too low. At the second sale the mine went to Corrigan, McKinney and Company (whose properties are now operated by the Republic Steel Corporation). This Company cyanided about 30,000 tons of the old tailings in 1900 and 1901. They recovered $54,682.38 in bullion, although a part of this may have been obtained from amalgam found around the old mill on the plates and elsewhere, as some of the old accounts suggest.

During the period of activity of the Ropes mine, prospecting and explorations on nearby lands were carried on, the most important discoveries lying a few miles west of the Ropes, where very rich specimens were found in Section 35, T48N–R28W, on properties which became known as the Michigan and the Superior. Shallow shafts were sunk, and tests made at the Ropes mill gave very satisfactory recoveries; one run of 28 tons yielded $8,400. Along this same general belt, besides the Michigan and Superior, were the Grayling, Peninsula, Gold Lake, Lake Superior, Gitchigamme, Grummet, Giant, Brown, Case, and others. The maximum activity in these prospects was prior to 1890.

In the early nineties, gold-bearing veins were discovered on the north side of the Dead River Valley, about nine miles north of Ishpeming. The most prominent of these explorations were the Fire Center, Beaver, and Crescent. Shallow shafts were sunk and some high grade material encountered, but the deposits were small and discontinuous.

Many other prospects of lesser interest were explored in this general area north of Ishpeming, and from time to time spectacular specimens were reported, but the values were bunchy.

With the closing of the Ropes mine in 1897, followed by the brief attempts to revive the property during the next two years and the cyaniding of a part of the tailings, all major activity in the district ceased until 1928, when Ishpeming men obtained a lease on the old Ropes property, and started ex-

plorations on the surface. In 1932 they secured leases on adjacent lands, and in 1933 organized the Ishpeming Gold Mining Company. They continued surface explorations on these lands until late in 1934, when the Calumet and Hecla Consolidated Copper Company took over their leases and bought into the Ishpeming Gold Mining Company. Calumet and Hecla unwatered the old mine, extended the drifts on the bottom level, diamond drilled the old mine from underground, and also carried on trenching and diamond drilling on surface. In 1941 Calumet and Hecla purchased the property and bought up the stock of the Ishpeming Gold Mining Company. At present no work is being carried on at the property because of war time restrictions on precious metal mining.

Other recent attempts to revive activity in the district were made by some individuals who took leases on the old Michigan gold property and later organized the Michigan Gold Mining Company. They unwatered and deepened one of the old shafts, and made some mill tests of the ore. Other individuals secured options on a considerable area north of the Michigan-Ropes belt, and spent a season prospecting, mapping, and drilling. Their activities were concentrated around the old Fire Center locations in Section 35, T49N–R27W. An attempt was also made to revive the Ten Kilns mine in Section 21, T48N–R27W. These projects were all started after the lease had been taken on the Ropes, and the properties are likewise dormant at present.

PRODUCTION.

The precious metal production of the district north of Ishpeming is as follows. About ten per cent of the Ropes production was silver; the remainder is gold.

Ropes Gold & Silver Company	$702,831.75
Michigan Gold Company	21,548.36
Fire Center Gold Mining Company	2,063.00
Various Prospects	820.00
Total	$727,263.11

BIBLIOGRAPHY.

Very little has been written on the gold deposits of Michigan in the geological literature, but considerable information of both historical and geological interest can be found in the annual publications known as the "Mineral Resources" and "Mineral Statistics" of Michigan of the years during which there was mining and prospecting activity; also in the files of the Iron Agitator, later the Ishpeming Iron Ore. These sources furnished most of the historical and statistical data in this paper.

GENERAL GEOLOGY.

The gold deposits of the Ropes-Michigan belt occur in an anticlinal area of Archean rocks about two miles in width, lying between the synclines of Huronian rocks, known as the Dead River, and the Marquette basins. The

Archean rocks consist of basic extrusives and associated fragmental phases, with minor acidic members, intruded by granite and peridotite. The deposits of the Fire Center area occur in similar rocks on the north side of the Dead River Basin. The intrusives are of Laurentian age, and the earlier complex, the Mona and Kitchi schists, of Keewatin age.[8]

Details of structure have not been worked out except very locally in the vicinity of some of the gold deposits. The prevailing deposit of glacial drift conceals the relations, and the drill holes and exploratory openings are in general too far apart to work out structural detail. The broader features as stated, however, are pretty well established.

The rocks are all altered to some extent, the lavas being sericitized, silicified, chloritized, and uralitized, and the peridotites serpentinized and rendered talcose. These various types of alterations will be referred to later.

Besides the primary rock minerals and their alteration products, there is locally a variety of introduced minerals, including native gold and silver, pyrite, chalcopyrite, sphalerite, galena, pyrrhotite, tetrahedrite, molybdenite, tourmaline, and scheelite.

GOLD OCCURRENCES.

Many occurrences of gold in Michigan have been reported. Some of them are from the glacial drift, and others from the Paleozoic sediments, but none of those which has come to the writer's attention has been of commercial interest. The more authentic and important occurrences have been in quartz veins in the pre-Keweenawan of the Upper Peninsula. The occurrences are fairly widespread, but the most important, based upon past history and future prospects, are in the area north of Ishpeming in Marquette County. In the light of present information, the old Ropes Mine would seem to be outstanding in its possibilities, although there are several others of secondary interest in the area.

In general the gold occurs in quartz veins, either striking nearly east-west themselves as at the Michigan and adjacent mines, or striking north of east as echelon veins in a nearly east-west shear zone, as at the Ropes. These veins are mostly in the basic volcanics of the Keewatin, although some of the minor occurrences are along quartz porphyry and granite contacts as at the Fire Center and the Peninsula. In one case, the Billings or Ten Kilns, the vein is in quartzite of Middle or Upper Huronian age. This occurrence, somewhat over a mile from the Ropes deposit, probably serves to date the gold mineralization of the entire area as of post-Middle Huronian age.

THE ROPES ORE BODY.

General Environment. The Ropes ore body lies in a nearly vertical tabular body of Keewatin schist standing in a shear zone between two intrusive peridotite masses of Laurentian age. (In this paper the former is referred to as "the Keewatin" and the latter, "the peridotite.") Because of its shape, position, and relationship to mineralization, the early miners called this

[8] Leith, C. K., Lund, Richard J., and Leith, Andrew: Pre-Cambrian Rocks of the Lake Superior Region. U. S. Geological Survey Prof. Paper 184, 1935.

body of Keewatin the "mineral dike." It rather certainly is connected with the main body of Keewatin rocks of similar type to the west of the mine, and it is known to extend eastward as far as the exploration has been carried, a distance of 1,900 feet from the shaft, Fig. 1. In the mine it varies up to 150 feet in thickness, and consists of the usual Keewatin rock types of this area; namely, basic lavas and fragmentals. Its position, attitude, and shape can be explained by regarding it as a wall of Keewatin left between the two peridotite bodies. However, both the schist remnant itself and the peridotite on each side are strongly sheared and altered. It is certain that there has been considerable movement along this shear zone, and probably the position, attitude, and shape of the Keewatin body in the shear zone are in part the result of the rock movements. Thus the evidence seems to point to both

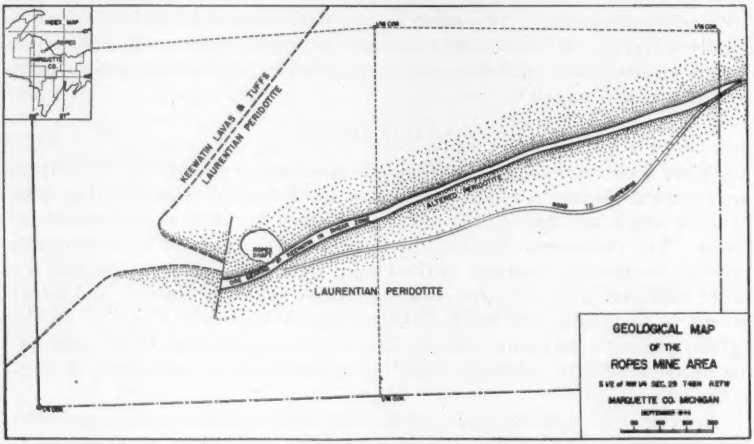


FIG. 1. Geological map of the Ropes Mine area.

intrusive activity and faulting as explaining the position, attitude, and relationships of the "mineral dike."

Rock Alteration. The rocks of the Ropes area have undergone alteration as a result of at least three processes (not including weathering). There is the alteration associated with the shearing, that associated with the action of the hydrothermal ore-depositing solutions, and probably earlier than these was a deuteric or autometamorphic alteration of the peridotite and associated contemporaneous contact metamorphism of the intruded rocks. Present studies are not extensive enough to differentiate sharply between the effects of these processes, nor are they sufficiently quantitative to place precise limits on the distribution of the different types of alteration. It is doubtful, however, whether these two objects could be attained completely even with considerable study, inasmuch as the literature on alteration of peridotite to talcose and serpentinized phases indicates that they may be formed by the several processes which have been operative in the Ropes area, and as to placing

limits on the areas of different alteration types, this would be difficult because of gradations in intensity of alteration and overlapping of types. Figure 2 shows the relations of these alteration processes diagrammatically.

1. *Serpentinization.* In the vicinity of the Ropes mine, the peridotite is thoroughly serpentinized for a width of some hundreds of feet in zones bordering on each side of the strong east-west shear zone running through the property. The color grades from a bright yellow green to a dull dark green. There are numerous irregular carbonate veins, and in places there have been attempts to quarry and market the rock as serpentine marble or verde antique.

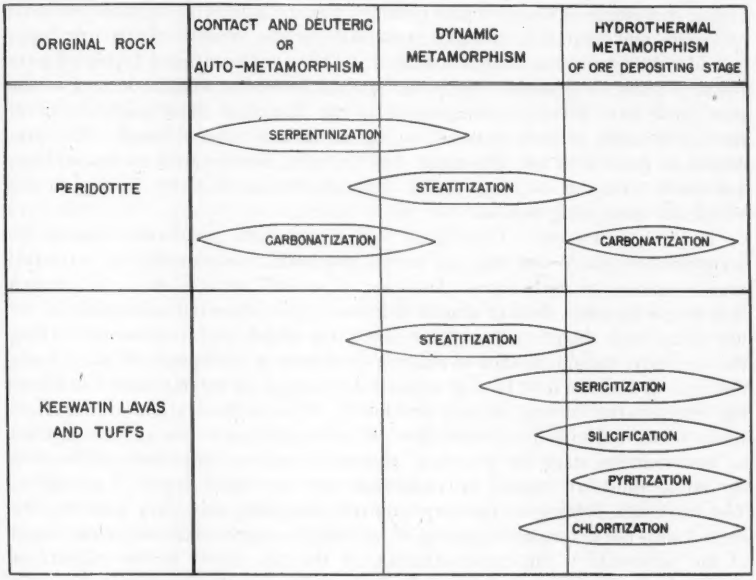


FIG. 2. Diagrammatic representation of rock alteration.

Veinlets of the fibrous serpentine occur and these have been examined at various times as possible sources of commercial asbestos. An undetermined platy mineral, probably brucite, locally accompanies the asbestos. This strong serpentinization becomes weaker away from the shear zone, and the peridotite has a fresher, blacker appearance, giving more of a ring when struck as contrasted with the dead sound of the serpentinized phase. Toward the shear zone it grades more rapidly into the talc schist. Other shear zones within the peridotite, not known to be associated with ore mineralization, also have associated serpentinization. This broader distribution of the serpentine suggests that it was formed by deuteric or autometamorphic processes, and perhaps to some extent by dynamic metamorphism rather than by hydrothermal processes associated with ore deposition.

2. *Steatitization.* Where the peridotite is strongly sheared it develops into a talc schist. This zone varies in width up to several hundred feet, and is bordered on both sides by the serpentinized zones in the less sheared peridotite. There are several phases of the talcose rocks, one of them being a fine grained massive to slightly schistose black rock, probably the steatitized equivalent of the fine grained marginal peridotite or of highly magnesian rocks of the Keewatin series. This rock is apparently made up almost entirely of talc. It forms a very smooth, non-gritty powder when ground, but the color is a dull greenish white, apparently rendering it undesirable for many of the commercial uses of talc. Of equal or greater abundance is a highly schistose phase, consisting of white to pale greenish foliated talc, with variable amounts of calcite and quartz, into which, especially in the vicinity of the ore body, considerable pyrite has been introduced. There are occasional layers of pure foliated white or greenish white talc several inches in thickness, and in the past these have given encouragement to the idea that there might be commercial deposits of such material, but so far none has been found. The predominant process in talc formation was probably the dynamic metamorphism associated with the shearing, and to a lesser degree the hydrothermal action of the ore-depositing period.

3. *Carbonatization.* The altered equivalents of the peridotite; namely, the serpentinized phase and the talc schist, are both characterized by a considerable amount of carbonate. Analyses of several veins show it to have a lime magnesia ratio close to that of dolomite. It is especially abundant in the talc schist near the contact with the Keewatin schist, and in diamond drilling the ore body, the appearance of massive carbonate in the core is in many cases the first sign of the hole having crossed the margin of the Keewatin and having entered the barren altered peridotite. The carbonization of the Keewatin rocks is decidedly subordinate. The assignment of the carbonatization to any definite stage in the rock alteration history encounters difficulties similar to those mentioned in connection with the other types of alteration. The carbonate veining in the serpentinized peridotite may very well be connected with the deformation period, if not with the earlier late-magmatic stages of the peridotite. The carbonatization of the talc schist in the vicinity of the ore body, however, may be of the hydrothermal, ore-depositing stage.

4. *Sericitization.* The Keewatin rocks in the shear zone in the vicinity of the ore body have been sericitized to a varying degree. Within the ore body itself, there is a rather definite relationship between the degree of sericitization and the gold content. Dr. C. O. Swanson was fairly successful in estimating comparative gold content from the degree of sericitization in numerous samples taken for assay. This probably indicates that the processes most active in forming sericite were the ones most active in depositing gold, and since the gold is late hydrothermal in origin, the sericite is also. However, the alternative must be kept in mind; namely, that the dynamic metamorphism in the shear zone sericitized certain rocks, and that those rocks most susceptible to sericitization were, later on, also most favorable for gold deposition.

5. *Silicification.* The Keewatin rocks in the shear zone are silicified and traversed by massive unsheared quartz veins of various widths, persistence,

and attitudes. In general, the silicification and quartz veining is most abundant in the ore body, although it persists well beyond the best part of the ore, in this respect resembling the pyritization. The stopes of the old operations were in lenticular quartz veins up to about 40 feet in thickness and 200 feet in length. These form the nucleus of the silicification, sericitization, pyritization, and gold impregnation of the Keewatin, and the carbonatization of the talc schist. The silicification and quartz vein formation belong to the period of introduction of the gold, and is, therefore, like the sericite and pyrite, of late hydrothermal origin.

6. *Pyritization.* In the vicinity of the ore body the Keewatin schist is impregnated with pyrite. There are three principal occurrences, as coarse crystals in the more massive or less schistose rocks, in lenses or layers of fine grained crystal aggregates in the more schistose phases, and as part of the filling in the quartz veins. Experience here confirms that reported from many other gold deposits in that the gold is in general more abundant where pyritization is most intense, except that where the pyrite occurs in coarse automorphic crystals, however abundant, the gold values are likely to be low or indifferent. The pyrite extends in the Keewatin well beyond the limits of the ore body. The talc schist also is pyritized to some extent, but much less than the Keewatin. The pyritization is regarded as of hydrothermal origin.

7. *Chloritization.* Chloritization is present, but the impression now is that it is subordinate to the other alteration types in amount. Further petrographic studies would be necessary before discussion of chloritization. The patches of chlorite extending along the plane of schistosity away from pyrite grains, which have been noted in thin sections from gold deposits elsewhere, are present in the rocks of this area. It is thought that the chloritization took place under about the same conditions as the sericitization.

Types of Ore. There are two distinct types of ore in the Ropes Mine; the quartz tetrahedrite veins, and the surrounding mineralized schist. These two types are different mineralogically and geologically, and will be described separately.

1. *Quartz-Tetrahedrite Type.* The production from the old Ropes Mine came from a series of nearly vertical quartz veins standing in echelon relationship with each other. They lie within the narrow, nearly vertical, tabular body of Keewatin lavas and volcanic fragmentals, which separates the two peridotite masses. This region between the peridotite masses has been strongly sheared, and as has been indicated, there is some question as to whether the existence and form of the separating wall of Keewatin schist are due chiefly to the intrusive activity on both sides, or to its having been faulted into position. The prevailing schistosity of the shear zone strikes nearly east-west. The old stopes indicate that the larger quartz veins strike about N. 65° E., and are lenticular, up to 38 feet thick, about 200 feet in extent horizontally, and about 250 feet vertically. There were about eight of these major shoots in the old mine, with some minor ones. The recent explorations have not disclosed any important additions to the quartz lenses already known and worked in the past, but they have demonstrated by diamond drilling that material of the same sort extends far below the bottom of the old mine.

The accessory minerals of these veins are chiefly pyrite and tetrahedrite, with minor amounts of chalcopyrite, galena, sphalerite, native silver and gold. More rarely may be seen tourmaline and molybdenite. No gold has been seen with the naked eye in the recent explorations, but visible gold is mentioned in the accounts of the older operations. Both silver and gold may be seen in polished sections, however. The gold is a pale yellow, and therefore probably alloyed with silver. Assays indicate that for the deposit as a whole there is about five times as much silver as gold, by weight. However, the silver ratio in the quartz veins is higher than this average five to one ratio, suggesting that the tetrahedrite in these veins is argentiferous.

The old Ropes mill stamped the rock to pass 50 mesh. Two products were obtained: bullion from amalgamation, and a mineral concentrate which was shipped to a smelter. About 80 per cent of the total gold, and 27 per cent of the total silver recovered, came from the amalgamation, and the remainder came from the concentrates. The total ore milled was about 215,000 tons, which yielded $647,902.37, about 90 per cent of which was gold, the remainder silver. (This does not include the $54,929.38 recovered by reworking some of the tailings after the mine shut down.) During the years for which both tonnage and recovery figures are available, 198,486 tons stamped yielded $601,110.58, or $3.03 per ton. This means that the recovery was about .132 oz. gold per ton and .3 oz. silver, with an indicated loss in the tailings as determined by recent sampling of about .06 oz. gold and .6 oz. silver. Therefore, the ore stamped ran .192 oz. gold and .90 oz. silver per ton, or, at $35.00 per oz. for gold and $0.70 per oz. for silver, it would now be worth $6.72 per ton in gold and $0.63 per ton in silver, a total of $7.35 precious metals.

Following is a table showing the production by years:

Year	Tons Stamped	Total Gold and Silver Recovered	Yield Per Ton
1881			
1882			
1883	200	$6,579.94	$10.00
1884			
1885	5,413	26,430.76	4.88
1886	6,959	43,153.85	6.20
1887	10,216	34,930.66	3.42
1888	16,855	57,684.75	3.42
1889	31,365	99,715.45	3.18
1890	31.578	79,568.27	2.52
1891	21.355	71,785.98	3.36
1892	21,794	59,603.90	2.735
1893	15,080	43,925.77	2.91
1894	21,185	45,465.77	2.15
1895		36,211.85	
1896	16,686	38,845.42	2.33
1897	Closed in July 1897	4,000.00	
1900 Tailings 1901 Retreatment		54,682.38	
1933 Ditto		247.00	
Total		$702,831.75	

2. *Pyritic Dissemination in Schist.* Surrounding the quartz tetrahedrite echelon veins is a halo of hydrothermally altered and pyritized schist which carries gold values. Locally the explorations have been sufficiently detailed to show the relative cross sectional areas of the quartz vein nuclei and the mineralized schist halo. Thus on one level the area of disseminated ore averaging $5.00 per ton precious metals, is 760 feet long, with an average width of about 38 feet. The quartz vein nucleus is about 200 feet long by 15 feet wide. This means that there is about eight times as much $5.00 pyritic schist ore as quartz vein ore on that level. If this ratio exists throughout the mine, there would be over one and one-half million tons of schist ore adjacent to the old stopes, from which about 200,000 tons of quartz vein material was extracted in the early operations.

This type of ore shows little variety in metallic minerals present, pyrite being practically the only one visible, even microscopically. The better gold values are associated with sericitization and silicification of the rock, and as has been mentioned, there is a rough quantitative relationship between the degree of sericitization and the gold content.

The values within the limits of the $5.00 ore body do not as a rule show wide or erratic variations. This is consistent with the fact that visible gold has not been reported from this type of ore. In general, the values do not drop off abruptly within the Keewatin schist itself, although if they extend up to the talc schist walls on either side of the ore formation they drop off sharply at the contact. Similarly, there are certain relatively impermeable rock types within the ore formation, which in most cases serve to cut off the values rather abruptly. These may be talcy or fine-grained phases, or they may be late diabase dikes which, while they are pre-mineral, are later than the schistosity, and therefore presented a dense inhospitable front toward the ore-depositing solutions.

It is probable that this disseminated ore was recognized at the time of the active mining of the quartz vein type, since many openings made in the search for the quartz veins were in it. It was not stoped however, for two conceivable reasons: first, that it was in general of lower grade; and second, that the values were almost impossible to recover by the amalgamation and gravity methods available at that time.

Exploration. The recent explorations were planned with several objectives in mind. Surface diamond drilling was undertaken to determine how far the ore extended laterally along the shear zone, and whether or not there were parallel ore bodies in the shear zone in the same cross section as the Ropes. No important extensions of the Ropes ore body were found, nor were parallel ore bodies discovered.

Not only were these broader objectives explored by surface drilling. The old mine was unwatered and a long drift was driven on the bottom level along the trend of the ore formation, with some crosscutting drilling to explore the entire width of the shear zone. While scattered mineralization was found, both along the strike of the leaf of Keewatin schist between the peridotite bodies, and in the talc schist within the shear zone adjacent to this leaf, the results were the same as with the surface drilling; namely, the values of eco-

nomic importance were found only in the vicinity of the Ropes quartz lenses. However, the Keewatin leaf was found to be narrower and to be pinching out eastward along the strike near surface; whereas it is wider and extends further in this direction on the 850 or bottom level. Quartz veinlets and gashes and pyrite content persist in the Keewatin as far as the drifting was carried, which to the eastward was over 400 feet beyond the limit of the gold concentration. Apparently silicification and pyritization extended further than the gold, although the fine pyrite and sericitization seem to be more closely confined to the ore bodies.

Thus the explorations for larger objectives were unsuccessful. However, these were only carried on from the surface and from the bottom level, leaving unanswered the question of whether the disseminated low values throughout the width of several hundred feet of talc schist adjacent to the known ore body may be a capping of more important values below.

Explorations for ore occurring as schist impregnation adjacent to the quartz veins were more successful, and it was developed by drifting, crosscutting, and diamond drilling. Horizontal crosscutting drill holes were spaced at hundred foot intervals along the bottom level. The ore body, having been outlined, intermediate holes were drilled, followed by crosscutting to obtain larger samples for checking the values. It was found that the large samples taken from the crosscuts assayed nearly sixty per cent higher than the drill core from the holes which the crosscuts followed.

After the bottom or fifteenth level was explored by these methods, the thirteenth and ninth levels were drilled in a similar fashion. The ninth level is about halfway down in the old mine; therefore this detailed exploration is all in the lower half of the mine. Assuming that the ore body is only half as large in the upper part of the mine as in the lower part, there are over one million tons of mineralized schist adjacent to the old stopes, from the surface down to a depth of 850 feet. This ore body averages 0.13 oz. gold and 0.7 oz. silver per ton.

What the situation may be at greater depth is not known. The same type of mineralization has been proved to go to great depths in other districts. At the Ropes mine underhand stoping was carried to a depth of over one hundred feet below the bottom level. Several diamond drill holes followed the ore body to greater depths, one of them reaching a depth of over 700 feet below the bottom level before passing into the side wall. These holes showed the same type of mineralization and rock alteration as occurs at higher levels, and the gold values were encouraging.

Structural Control of Ore Body. The geological features which are associated with the Ropes ore body, and which may in some degree have been effective in localizing it, are the shear zone, the tabular body of Keewatin schist, the stresses determining the loci of the echelon quartz veins, the near-by porphyry intrusions, the flat thrust faults cutting the schist, certain diabasic or "lamprophyre" dikes found in the ore body, and locally, barrier effects.

The shear zone is some hundreds of feet in width, and its known horizontal extent is several thousand feet, with no known limits at either end, nor in depth. It is a major structural feature, and doubtless should be given first

place among the mineralization controls. It was the conduit of the ore-depositing solutions.

Perhaps next in importance is the presence of the favorable host rock, the Keewatin schist inclusion, in the shear zone. So far as known the commercial ore is restricted to this schist as distinguished from the enclosing talc schist derived from the peridotite. The Keewatin schist body becomes wider and longer in depth, pinching down near the surface, thus forming an inverted funnel, which may have had a favorable effect on solution concentration. That such a barrier control may be effective is indicated by a concentration of values on a smaller scale beneath or against impermeable walls, especially where they converge upward.

The echelon strains forming the loci of the quartz veins may have exercised an important control in the ore localization. They form the nuclei of the ore body, and seem to be the one feature which gives out longitudinally along the Keewatin schist as the values decline. The Keewatin schist as a geological unit is slightly warped in a vertical plane where the ore body occurs. It dips slightly south from the vertical in the upper levels, and slightly north from the vertical in the lower levels. This warping may have had its effect in localizing the ore.

It is more difficult to evaluate the importance of the other geological features mentioned as possibly having an effect in ore localization. While acidic intrusives are present in the general area, none have been found which seem to be related to the shear zone, much less the ore body, although the mineralization at the old Peninsula mine, between the Michigan and Ropes, lies in a small granite area. More to the point is the fact that any acidic intrusive which is responsible for the mineralization must be post-Middle Huronian, and all of those known in the vicinity are mapped as Archean, so far as the writer is aware. The flat thrust faults displace the ore body, but no connection between values and faulting has been observed, and the deeper drill holes below the old workings show mineralization to persist in depth below the most conspicuous of these faults so far encountered. Likewise, no connection between ore and the lamprophyre dikes has been found. These dikes cross the sheared Keewatin, and are much less deformed and altered. They carry low gold values where they occur adjacent to ore, and are barren where they are outside of the ore body. Thus they seem to be later than the schistosity but prior to the introduction of gold, and to have no genetic connection with the ore.

Genetic Classification. The Ropes ore body has the general characteristics of the gold deposits of the mesothermal group as defined by Lindgren.[4] The simple sulphides with tetrahedrite; high silver content both of the gold and the other metallic minerals; the sericitization, silicification, and carbonatization of the wall rocks; the lack of pyrrhotite and metallic oxides; the almost entire absence of tourmaline and molybdenite; and the absence of pyroxenes, amphiboles, and garnets, all are features which place the deposit in the mesothermal group. Therefore, it resembles the gold veins of Cali-

[4] Lindgren, Waldemar: Mineral Deposits, McGraw-Hill Book Company, New York, 1933.

fornia rather than those of the Homestake of South Dakota or the Porcupine district of Ontario. Zoning has not been recognized within the Ropes ore body itself, although in other occurrences to the westward, tetrahedrite is not present, and tourmaline, molybdenite, and pyrrhotite are common. Thus at the Michigan Gold Mine, 2½ miles west of the Ropes mine, the silver ratio is much lower; tetrahedrite is absent; and in addition to pyrite, chalcopyrite, galena, and sphalerite, the higher temperature minerals; pyrrhotite, molybdenite, scheelite, and tourmaline also are present. Thus there is a broad district zoning of the gold deposits, the ore body of the Michigan mine approaching the hypothermal type, and the Ropes being of the mesothermal type.

Possible By-Products. If gold mining operations should ever be started at the Ropes property, it might be possible to produce and market some by-products. Among these, dark talc and certain rock types possibly suitable for roofing granules have the most chances of being economic. The dolomite, serpentine asbestos, and light colored talc are less likely to be commercial. Nickel and chromium are present in the peridotite in amounts too small to be commercial. There is some evidence that the nickel is in the silicates. Much of the drill core, especially that in the gold ore body, was examined under ultra-violet light without anything of interest being disclosed. Spectrographic tests were made for metals of the platinum group, but they were negative.

CALUMET, MICHIGAN,
September 15, 1944.

MANGANESE CONTENT OF THE SHADY DOLOMITE IN BUMPASS COVE, TENNESSEE.

JOHN RODGERS.*

ABSTRACT.

The Shady dolomite in Bumpass Cove, Tennessee, contains deposits of hydrothermal sulphide minerals, and its residual clay contains oxidized manganese deposits. New chemical evidence bearing on the source of this manganese is presented.

Chemical analyses of isolated components of sulphide-bearing dolomite show that the percentage of manganese is highest in country-rock dolomite unaffected by hydrothermal action, and that the manganese is present as carbonate. Manganese determinations on samples from a drill hole show that 43 feet of beds, about 100 feet above the base of the Shady dolomite, average 0.6 per cent manganese oxide, and that adjacent beds carry smaller amounts. Manganese carbonate, deposited with the original carbonate rock, is therefore considered to be the source of the manganese deposits of Bumpass Cove.

THE writer has recently been engaged in a study of the manganese deposits of Bumpass Cove, Unicoi and Washington Counties, Tennessee, and the following note presents the results of some chemical analyses which were made during the course of the study in the hope of determining the source of the manganese. A full report on the geology and mineral resources of Bumpass Cove will shortly be published as a bulletin of the Tennessee Division of Geology. The writer wishes to acknowledge his indebtedness to Mr. D. F. Hewett, Mr. Hugh D. Miser, Mr. Charles H. Behre, Jr., and Mr. Philip B. King of the U. S. Geological Survey, who have encouraged him in pursuing the problem and have critically read the manuscript of this note.

The manganese deposits in the residual clay of the Shady dolomite in the southern Appalachians, of which the deposits in Bumpass Cove are examples, have been studied for many years. There has been general agreement that the oxidized manganese minerals forming the commercial deposits were formed during the weathering that produced the residual clay, but there has been no unanimity concerning the original source of the manganese. Harder [1] suggested that the manganese was originally present in overlying formations, particularly the shale of the immediately overlying Rome formation. Stose, Miser, Katz, and Hewett [2] concluded that the manganese was originally disseminated in the basal part of the Shady dolomite, and Stose and Schrader [3]

* Published with the permission of the Director, Geological Survey, U. S. Department of the Interior.

[1] Harder, E. C.: Manganese deposits of the United States. U. S. Geol. Surv. Bull. 427: 101, 1910.

[2] Stose, G. W., Miser, H. D., Katz, F. J., and Hewett, D. F.: Manganese deposits of the west foot of the Blue Ridge, Virginia. Va. Geol. Surv. Bull. 17: 54–55, 1919.

[3] Stose, G. W., and Schrader, F. C.: Manganese deposits of east Tennessee. U. S. Geol. Surv. Bull. 737: 25, 1923.

suggested that much of it came from the immediately underlying shale and siltstone ("transition beds" to the Erwin formation). As a result of his studies in the Cartersville district in Georgia, Kesler [4] has recently suggested that the manganese there was derived from a hydrothermal mineral or minerals introduced with other hydrothermal minerals along lines of structural weakness. In a still more recent publication, King and others [5] report the results of analyses made on specimens collected from surface outcrops of the Shady dolomite by Laurence and by King, which indicate that that part of the Shady dolomite which is 100 to 200 feet above the base contains manganese in sufficient quantity to provide an adequate source for the known deposits. The chemical analyses reported in the present note offer further evidence as to the state of combination of this manganese and its stratrigraphic distribution.

The Shady dolomite of Bumpass Cove very commonly contains veins, blebs, and stringers of white coarsely crystalline dolomite which may be designated "sparry dolomite" to distinguish it from the finer-grained country rock. In addition, sphalerite, galena, and pyrite, presumably of hydrothermal origin, occur in places disseminated in the dolomite. As the rocks carrying sulphides were found by analysis to contain small amounts of manganese, it seemed desirable to determine the state of combination of the manganese. Selected samples containing from 5 to 10 per cent of sulphide minerals were taken in the Jackson mine in Bumpass Cove and submitted to Professor S. J. Shand of Columbia University for study. From these samples, Professor Shand prepared powdered samples of country rock, of sparry dolomite, of sphalerite, and pyrite for analysis.

In preparing the carbonate powders, chips of country rock only slightly contaminated with sparry dolomite and of sparry dolomite practically free from country rock were broken down to fragments 2 to 4 millimeters across and were cleaned of sulphide minerals by careful inspection under a hand lens. This material was then ground to powder in stages, being inspected for sulphides at each stage. As no sulphides were recognized in the powder, the cleaning was virtually complete. The powders were dissolved in dilute hydrochloric acid and analyzed. According to Professor Shand,[6] "the insoluble residue was examined under the microscope and found to be chiefly quartz with some specks of opaque iron oxide. As the iron and mangenese found in these analyses were easily dissolved by hydrochloric acid, both must have been present in the form of carbonate." The analyses are given below.

The close similarity, except in insoluble material, between the analysis of the country rock dolomite and that of the sparry dolomite strongly suggests that the sparry dolomite formed by solution and redeposition of the country rock dolomite, without the introduction of any additional carbonate, and that its manganese content was entirely derived from manganese originally present in the country rock.

[4] Kesler, T. L.: Structure and ore deposition at Cartersville, Georgia. A. I. M. E. Trans. 144: 276–293, 1941.

[5] King, P. B., Ferguson, H. W., Craig, L. C., and Rodgers, John: Geology and manganese deposits of northeastern Tennessee. Tenn. Div. Geol. Bull. 52, 1944.

[6] Personal communication, November 18, 1943.

ANALYSES OF SAMPLES OF DOLOMITE FROM JACKSON MINE, BUMPASS COVE, TENNESSEE.
[S. J. Shand, analyst.]

	Country Rock.	Sparry Dolomite.
CaO	28.82	29.55
MgO	19.59	20.38
SrO	not detected	not detected
FeO	1.07	1.02
MnO	0.21	0.12
CO_2*	45.01	46.40
Insoluble	4.96	2.45
Total	99.66	99.92

* CO_2 determined by ignition (corrected for oxidation of ferrous oxide); it probably includes a little moisture which was not separately determined.

SAME, RECALCULATED TO CARBONATES, OMITTING INSOLUBLE MATERIAL.

	Country Rock.	Sparry Dolomite.	Theoretical Dolomite.
$CaCO_3$	54.36	54.19	54.34
$MgCO_3$	43.47	43.94	45.66
$FeCO_3$	1.81	1.68	—
$MnCO_3$	0.36	0.19	—
Total	100.00	100.00	100.00

The powders of the sulphide minerals were prepared in a similar manner by careful sorting under a hand lens. In addition the pyrite was cleaned by boiling in hydrochloric acid. Final inspection indicated that practically no impurities remained. The powders were dissolved in nitric acid and analyzed colorimetrically for manganese. According to Professor Shand,[7] "the coloration was so faint that it was obvious there was no more than a trace of manganese in each ore." The results are given below.

MANGANESE CONTENT OF SULPHIDE MINERALS FROM JACKSON MINE, BUMPASS COVE, TENNESSEE.
[S. J. Shand, analyst.]

	Sphalerite.	Pyrite.
Per cent Mn	0.005	0.0025
Recalculated to per cent MnO	0.007	0.0033

An opportunity to determine the stratigraphic distribution of manganese in the Shady dolomite and in part of the underlying Erwin formation arose when the U. S. Bureau of Mines drilled a 390-foot diamond drill hole close to the Jackson mine in Bumpass Cove. Through the courtesy of Harold B. Ewoldt, District Engineer, and Richard L. Sayrs, Project Engineer for the Bureau of Mines, the core of this hole was turned over to the U. S. Geological Survey and the Tennessee Division of Geology for study. The core was sampled and the samples were analyzed for manganese in the laboratory of the U. S. Geological Survey. In making these analyses, the samples were dissolved in concentrated acid; however, second portions of certain of the dolomite samples were dissolved in dilute nitric acid and analyzed. As the results of the second set of analyses checked closely with the results of the

[7] Personal communication, April 6, 1944.

LOG AND MANGANESE CONTENT OF CORE OF U. S. BUREAU OF MINES DIAMOND DRILL HOLE, JACKSON MINE, BUMPASS COVE, TENNESSEE.
[W. W. Brannock, analyst.]

Limits of Unit (depth in feet)	Description of Unit	Limits of Sample (depth in feet)	% MnO
0–59	Overburden Gravel and residual clay		
	SHADY DOLOMITE Upper white member		
59–72	Dolomite, light gray, fine-grained, massive; sparry dolomite forms blebs and streaks		
72–104½	Dolomite, light gray to blue-gray, fine- to medium-grained, in part faintly "ribboned"; sparry dolomite forms blebs and stringers		
		104–107	0.23
104½–110	Dolomite, medium blue-gray, strongly "ribboned"; sparry dolomite forms blebs and a few thin veinlets	107–110	0.33
110–120	Dolomite, light gray, fine-grained, fairly massive but mottled with slightly darker dolomite; has some silty partings. Sparry dolomite forms large blebs and veins. Sheared at base	110–115	0.28
		115–120	0.19
120–121	Dolomite, medium blue-gray, fine-grained, badly sheared along several fault planes; sparry dolomite forms thin veinlets along fractures		
		120–125	0.24
121–138½	Dolomite, light gray to white, medium- to coarse-grained, massive; near top some darker finer-grained mottled dolomite. Sparry dolomite forms poorly defined areas scattered through unit, also a few veinlets. Badly weathered; many mud seams. Shear zone at 135 feet	125–131	0.25
		131–138½	0.23
	Upper blue member	138½–143½	0.48
138½–153½	Dolomite, medium to dark blue-gray, fine- to medium-grained, strongly "ribboned" except close to top; some silty laminæ. Sparry dolomite forms blebs and stringers parallel to "ribbons." Grades down into underlying unit	143½–148½	0.44
		148½–153½	0.35
		153½–158	0.33
153½–180	Dolomite, dark to medium blue-gray, fine-grained, forming fragments in a breccia whose matrix is sparry dolomite. Shows "ribboned" structure in a few places	158–162	0.34
		162–167	0.41
		167–171½	0.49
		171½–176	0.63
		176–180	0.61
180–181	Dolomite, medium to light blue-gray, vaguely mottled, medium-grained		
		180–185	0.42
	"Ribboned" member		
181–189½	Dolomite, medium blue-gray, fine-grained, conspicuously "ribboned"; sparry dolomite forms blebs and stringers, mostly parallel to "ribbons"	185–189½	0.54
189½–196½	Dolomite, dark to medium blue-gray, fine-grained, partly "ribboned," partly brecciated, grading into units above and below. Sparry dolomite forms matrix to breccia and replaces some "ribbons"	189½–194	0.72
		194–199	0.63

LOG AND MANGANESE CONTENT OF CORE OF U. S. BUREAU OF MINES DIAMOND DRILL HOLE, JACKSON MINE, BUMPASS COVE, TENNESSEE.—(*continued*)

Limits of Unit (depth in feet)	Description of Unit	Limits of Sample (depth in feet)	% MnO
	SHADY DOLOMITE—*Continued*		
	"Ribboned" member—*Continued*		
196½–203½	Dolomite, medium to dark blue-gray, fine-grained, conspicuously "ribboned"; sparry dolomite forms blebs and stringers parallel to "ribbons"	199–203½	0.51
203½–226½	Dolomite, dark to medium blue-gray, fine-grained, chiefly brecciated but some is well "ribboned," especially at top. Sparry dolomite forms matrix of breccia and replaces "ribbons"	203½–209	0.72
		209–213	0.83
		213–217	0.71
		217–222	0.61
		222–226½	0.61
226½–230½	Dolomite, medium blue-gray, fine-grained, conspicuously "ribboned"; sparry dolomite forms blebs parallel to "ribbons," also a few veinlets	226½–230½	0.27
	Lower blue member		
230½–272	Dolomite, dark to medium blue-gray, fine-grained, irregularly "ribboned," brecciated in places; sparry dolomite forms blebs and stringers parallel to "ribbons"	230½–235½	0.29
		235½–240	0.39
		240–245	0.36
		245–250	0.40
		250–255	0.30
		255–260	0.27
		260–265	0.23
		265–270	0.36
272–279½	Dolomite, dark to medium blue-gray, fine-grained, ranges from poorly "ribboned" to somewhat brecciated. Sparry dolomite forms blebs and matrix to breccia, but is much less abundant than above	270–275	0.32
		275–279½	0.32
	Lower white member		
279½–305	Dolomite, light gray, rarely light blue-gray, chiefly medium-grained but ranges from fine- to coarse-grained; shows vague color banding and many stylolitic partings. No sparry dolomite	279½–285	0.13
		285–290	0.18
		290–295	0.18
		295–300	0.18
		300–305	0.17
305–308	Dolomite, light gray to light blue-gray, medium- to fine-grained; one foot at top and one at base well banded and full of glauconite grains; middle foot massive	305–308	0.27
308–313	Dolomite, light gray, medium- to fine-grained; some color banding and a few silty partings; layer with glauconite grains near top	308–313	0.19
313–316	Dolomite, light gray to white, medium- to coarse-grained, well banded. Much glauconite in some layers, none in others. No quartz grains seen	313–316	0.18

first set, it can be assumed that all the manganese present in the dolomite samples was in a soluble form, almost certainly manganous carbonate.

In that phase of the Shady dolomite referred to below as "ribboned," layers of light blue-gray and dark blue-gray dolomite alternate, most of them

LOG AND MANGANESE CONTENT OF CORE OF U. S. BUREAU OF MINES DIAMOND DRILL HOLE, JACKSON MINE, BUMPASS COVE, TENNESSEE.—(*continued*)

Limits of Unit (depth in feet)	Description of Unit	Limits of Sample (depth in feet)	% MnO
	ERWIN FORMATION		
	Helenmode member [8]		
316–324½	Coarse well rounded quartz grains in cement of light gray dolomite. Probably some silt below, some glauconite above. Pink cast at base	316–320	0.15
		320–324½	0.15
324½–326	Rounded quartz grains in red silty matrix; some dolomite cement except at base. Grades into underlying unit	324½–327	0.20
326–330½	Siltstone, red; some quartz grains above. Color change at base is gradational, red bands alternating with green	327–330½	0.05
330½–344	Siltstone, green, mottled. Red streaks from 337 to 338 and from 340 to 342. Toward base, thin quartzite layers appear and unit grades into underlying unit	330½–337	0.06
		337–344	0.04
344–378½	Siltstone and quartzite, alternating in thin layers. Siltstone is dark and greenish and contains some quartz grains; quartzite is light-colored. More and more quartzite below	344–350½	0.05
		350½–357	0.04
		357–364	0.05
		364–371	0.03
		371–378½	0.05
	Upper quartzite member		
378½–390	Quartzite, white, massive, virtually pure	378½–390	0.02

being less than half an inch thick. Sparry dolomite in this phase of the Shady occurs almost exclusively in the light-colored layers which it may entirely replace, thus heightening the color contrast between adjacent "ribbons."

The log of the core and the results of the analyses are given below. The summary of the log gives the true thickness of the larger units, corrected for the dip of the bedding; through most of the core the dip averages 25°, but near the bottom it is much less. The core is now stored at the offices of the

SUMMARY

Unit	True Thickness (in feet)	Average % MnO
Shady dolomite		
Upper white member	75 present, 32½ sampled	0.25
Upper blue member	38½	0.45
"Ribboned" member	43	0.60
Lower blue member	47	0.31
Lower white member	34½	0.18
Erwin formation		
Helenmode member	61½	0.07
Upper quartzite member	11 present and sampled	0.02

[8] The Helenmode member of the Erwin formation is named and described in King, P. B., Ferguson, H. W., Craig, L. C., and Rodgers, John: Geology and manganese deposits of northeastern Tennessee. Tenn. Div. Geol. Bull. 52, 1944.

Tennessee Division of Geology in Nashville and may be examined by any interested person.

These analyses appear to offer virtually conclusive proof that manganese carbonate, deposited with the original carbonate rock that is now the Shady dolomite, especially in and near the "ribboned" member, is the ultimate source of the manganese deposits of Bumpass Cove. Moreover, taken with the results of the analyses reported by King and others [9] on samples collected elsewhere in northeast Tennessee, they strongly suggest the same source for the other manganese deposits that occur in the residual clay of the Shady dolomite in the southern Appalachians.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.,
September 27, 1944.

[9] King and others, op. cit.

THE PRESENCE OF BERYLLIUM AND ASSOCIATED CHEMICAL ELEMENTS IN THE WALLROCKS OF SOME NEW ENGLAND PEGMATITES.

W. C. STOLL.

ABSTRACT.

Samples of mica-schist and mica-gneiss wall rocks of some New England pegmatites were found, by spectrographic analysis, to contain lithium, beryllium, zinc, tin, lead, columbium, molybdenum, and cerium in extremely low concentrations. The highest concentration of beryllium obtained was 0.0021 percent Be. It is thought likely that these elements were added to the wall rocks by solutions emanating from nearby channels of circulation of pegmatitic liquors during the time of emplacement of the pegmatite bodies. At least part of the added chemical elements found lodging as minor elements within common, rock-forming minerals, possibly as a result of recrystallization of these minerals in the presence of the introduced solutions.

INTRODUCTION.

DURING the course of an investigation of the distribution of beryllium as a minor element in mineral deposits and their adjoining rocks, which was carried on in the field and at the Massachusetts Institute of Technology from May 1941 to May 1942, beryllium and other chemical elements of pegmatitic affiliation were found to exist in extremely low percentages in the wall rocks of some New England pegmatites. This paper presents analytical data and an explanation of this minor occurrence of beryllium and accompanying elements.

The action of pegmatitic solutions upon the rocks with which they have come in contact is indicated by the presence in the rocks of minerals that, for reasons of their chemical composition, proximity to the pegmatite body, and textural relations within the rock, are supposed to have had an origin dependent upon the introduction of the pegmatite. The composition of a contact-metamorphic mineral may indicate that a transfer of pegmatitic material to the wall rocks has taken place, but, on the other hand, chemical or spectrographic analysis may perhaps indicate such additions of material even in the absence of contact-metamorphic minerals. From the data presented herein a conclusion is drawn that beryllium and other elements were added to the wall rocks of pegmatite deposits as a result of processes accompanying the emplacement of the adjacent pegmatites themselves. Such introductions have here taken place, to some extent, without the growth in the contact zones of minerals that contain the introduced elements as essential constituents. Some of the elements appear to have found lodging within the preexisting rock-forming minerals.

Sampling of the wall rocks originally was undertaken in order to determine whether they would, in some places, constitute a low-grade beryllium ore,

and, after the analytical results were known, no opportunity was had to revisit the localities. Thus, analyses of country-rock samples taken from points distant from the pegmatite outcrops, which would form standards of composition by which additions of material could be measured, are not available, and the conclusion that the elements under discussion were added to the wall rocks by pegmatitic solutions can be offered only in a tentative way.

SAMPLES AND ANALYSES.

A number of New England pegmatites were visited, and samples of mica schist or mica gneiss were taken at ten localities in Maine, five in southern New Hampshire, and two in Connecticut. The localities, with references to geological descriptions in the literature, are listed in Table 1.

TABLE 1.

LIST OF NEW ENGLAND PEGMATITE LOCALITIES SAMPLED, WITH REFERENCES TO DESCRIPTIVE LITERATURE.

Locality.	Reference.
Golding's Feldspar Quarry, near Bay Point Landing, Georgetown, Sagadahoc County, Maine	*Bastin, pp. 105–108
G. B. Willes Quarry, near Cathance Station, Topsham, Sagadahoc County, Maine	Bastin, pp. 115–116
Mt. Apatite Quarries, Auburn, Androscoggin County, Maine	Bastin, pp. 49–59
Mt. Mica, Paris, Oxford County, Maine	Bastin, pp. 81–93
Witt Hill, Millettville, near Norway, Maine	
Alvin Brown Farm, Millettville, near Norway, Maine	
Tamminen Farm, at foot of Mt. Noyes, Greenwood, Maine	
Harvard Quarry, Mt. Noyes, Greenwood, Maine	*Landes, pp. 399–411
Bennett Quarry, Buckfield, Maine	Landes, pp. 360–398
Hibbs Quarry, Hebron, Oxford County, Maine	Bastin, pp. 73–74
Palermo Mine, near North Groton, Grafton County, New Hampshire	*Sterrett, pp. 130–133
DeMott Mine, Prescott Hill, near Grafton, Grafton County, New Hampshire	Sterrett, p. 146
Belloir Mine, 1.5 miles northwest of Grafton Center, Grafton County, New Hampshire	
Beryl Mountain, near South Acworth, New Hampshire	
Jehial White Mine, near Gilsum, Cheshire County, New Hampshire	Sterrett, pp. 115–116
Strickland Quarry, Collins Hill, near Portland, Middlesex County, Connecticut	Sterrett, pp. 65–67
George Roebling Mine, near Merryall, east of South Kent, Litchfield County, Connecticut	Sterrett, pp. 63–65

* References are as follows: BASTIN, E. S.: Geology of the Pegmatites and Associated Rocks of Maine. U. S. G. S. Bul. 445, 1911; LANDES, K. K.: The Paragenesis of the Granite Pegmatites of Central Maine. Amer. Min., 10, 11, 1925, pp. 355–411; STERRETT, D. B.: Mica Deposits of the United States. U. S. G. S. Bul. 740, 1923.

The samples of schist and gneiss are typical of the metamorphic rocks in the areas visited. At some places the influence of the pegmatite on the rocks could be seen in the presence of metacrysts of garnet, black tourmaline, hornblende, or apatite. Wallrock samples were all taken as close as possible to pegmatite contacts. With a few exceptions they represent material that lay within 20 feet of a contact, but a small number of samples were taken at distances of thirty to several hundred feet from an exposure of pegmatite. The samples consist of fragments of rock chipped from the outcrops at more or less regular intervals. The number of samples taken at a locality de-

pended upon the number and size of the wallrock exposures, but it is probable that the aggregate of samples taken at each locality is fairly representative of the wall rocks exposed there.

Spectrographic analyses of the samples were made in the Cabot Spectrographic Laboratory, Geology Department, Massachusetts Institute of Technology. Analyses for beryllium were made quantitatively. Analyses for the accompanying minor elements were made semi-quantitatively, wherein relative concentrations of an element among a number of similar samples were judged by visual estimation of the intensities of the appropriate spectral lines in the spectrogram of each sample.

Of wallrock samples collected from 17 New England pegmatites, samples

TABLE 2.

QUANTITATIVE SPECTROGRAPHIC ANALYSES FOR BERYLLIUM IN THE WALLROCKS OF FOUR NEW ENGLAND GRANITE-PEGMATITES.

	% Be.
New Hampshire	
DeMott Mine, Prescott Hill, near Grafton	
Gneiss (quartz, feldspar, biotite)	0.00048
Gneiss (quartz, feldspar, biotite)	0.00068
Schist (muscovite, quartz)	0.00064
*Muscovite from this schist sample	0.00096
Gneiss (feldspar, quartz, muscovite, biotite)	0.00072
Quartz-feldspar mixture picked from this gneiss sample	present
Muscovite picked from this gneiss sample	present
Biotite picked from this gneiss sample	present
Gneiss (quartz, feldspar, mica)	0.00054
Gneiss (quartz, mica, feldspar, garnet)	absent?
Composite sample of the above 6 rock samples	0.00054
Schist (biotite, muscovite, with quartz veinlets)	absent
Belloir Quarry, northwest of Grafton Center	
Schist (biotite, quartz, with hornblende metacrysts)	0.00042
Gneiss (quartz, feldspar, biotite, muscovite, garnet)	0.00056
Schist (mica, quartz, feldspar, hornblende metacrysts)	absent?
Schist, same	0.00049
Schist, same	0.00038
Gneiss (quartz, feldspar, biotite, muscovite, with tourmaline, apatite, and garnet)	absent
Composite sample of above six samples	0.00038
Schist (biotite, muscovite, quartz, feldspar)	absent
Schist (biotite, quartz)	0.0012
Biotite picked from this schist sample	0.0012
Schist (biotite, quartz, feldspar, with tourmaline)	0.00060
Schist (mica, quartz, feldspar)	absent
Schist (biotite, quartz, feldspar)	absent
Schist (biotite, quartz, tourmaline)	absent?
Composite sample of above 6 rock samples	0.00051
Connecticut	
Strickland Quarry, near Portland	
Composite of 6 samples of biotite-quartz schist	absent
Composite of 4 samples of biotite-quartz schist	0.0021
Roebling Mine, Merryall, east of South Kent	
Composite of 6 samples of biotite schist	absent
Composite of 6 samples of biotite-quartz-feldspar-garnet schist	0.00037

*Samples of clean mineral were segregated from the rock by hand under the binocular microscope.

from four mines, the DeMott mine and Belloir mine in New Hampshire and the Strickland and Roebling quarries in Connecticut, contain beryllium. The highest concentration obtained was 0.0021 per cent Be (0.0058 per cent BeO). Samples from the other 13 localities, in Maine and New Hampshire, contain no beryllium that could be detected by the method used. Abbreviated descriptions of the wallrock samples which contain beryllium and the amounts of contained beryllium are given in Table 2.

In addition to beryllium, nineteen other minor elements were investigated in the spectrograms of each sample of schist and gneiss from all of the pegmatite localities listed. The twenty minor elements are classified in Table 3, according to their frequency of occurrence in the samples and according to their positions in the periodic table of chemical elements.

TABLE 3.

MINOR CHEMICAL ELEMENTS PRESENT IN THE WALLROCKS OF SEVENTEEN NEW ENGLAND PEGMATITES.

Class 1: Minor elements present in all of the samples analyzed

Periodic Group							
I	II	III	IV	V	VI	VII	VIII
copper	strontium barium	scandium yttrium	titanium	(vanadium)*	chromium	manganese	(cobalt)* (nickel)*

* Vanadium, cobalt, and nickel are each present in all but one sample.

Class 2: Minor elements present in some samples and absent in others

Periodic Group						
I	II	III	IV	V	VI	Rare Earth
lithium	beryllium zinc	(gallium)*	tin lead	columbium	molybdenum	cerium

* Gallium is present in most of the samples.

As judged from pronounced differences between the spectral-line intensities of the minor elements of the two classes, those elements present in all of the samples (*i.e.*, Class 1) are, with the exception of yttrium, present in relatively large amounts as compared with the elements of irregular or spotty occurrence (*i.e.*, Class 2). The elements of the latter class, where present, exist in extremely small concentrations, as, for instance, beryllium, quantitative analyses for which are shown in Table 2.

In Table 4 is given a reclassification of the chemical elements of Class 2, according to their presence or absence at each locality.

CONCLUSION.

In Table 3, the minor chemical elements that were found to exist in the wall rocks of some New England pegmatites were classified into two groups, based on their presence in all or only in part of the samples analyzed. The elements of Class 2 (*i.e.*, lithium, beryllium, zinc, gallium, tin, lead, columbium, molybdenum, and cerium) are of erratic distribution in the samples, suggestive perhaps of mineralization; and they are, with the exception of

TABLE 4.

SUITES OF SELECTED MINOR ELEMENTS IN THE WALLROCKS OF SEVENTEEN NEW ENGLAND PEGMATITES.

Locality.	Minor Elements of Class 2 * Present and Absent in Wallrock Samples.
DeMott Mine, N. H.	Lithium, beryllium (zinc),† tin (lead),† columbium, and cerium present; molybdenum absent
Belloir Mine, N. H.	Lithium, beryllium (zinc),† tin, columbium, and cerium present; molybdenum and lead absent
Strickland Quarry, Conn.	Lithium, beryllium, zinc, lead, molybdenum, and cerium present; tin and columbium absent
Roebling Quarry, Conn.	Lithium, beryllium, zinc, lead, and cerium present; tin, columbium, and molybdenum absent
Beryl Mountain, N. H.	All elements of Class 2 absent
Golding Quarry, Maine G. B. Willes Quarry, Maine Jehial White Quarry, N. H.	Cerium present; all other Class 2 elements absent
Mount Apatite Quarries, Maine	Lithium present; all other Class 2 elements absent
Tamminen Farm, Maine Harvard Quarry, Maine Hibbs Quarry, Maine Palermo Mine, N. H.	Cerium and lithium present; all other Class 2 elements absent
Bennett Quarry, Maine	Cerium, lithium, and columbium present; all other Class 2 elements absent
Alvin Brown Farm, Maine	Cerium and tin present; all other Class 2 elements absent
Mount Mica, Maine	Cerium, lithium, and zinc present; all other Class 2 elements absent
Witt Hill, Maine	Molybdenum present; all other Class 2 elements absent

* Refer to Table 3.

† The elements in parentheses are of extremely erratic and scanty distribution in samples from the localities indicated.

gallium, lead, and zinc, typically of granite-pegmatite affiliation or habitat. For these reasons it is thought likely that lithium, beryllium, tin, columbium, molybdenum, and cerium, and possibly also zinc and lead, were added to the wall rocks by solutions of pegmatitic origin. The elements of Class 1 are probably, for the most part, indigenous to the rocks.

The presence in some of the rocks of tourmaline and apatite indicates that boron and phosphorus were also added, although these elements were not investigated spectrographically. Aside from the porphyroblastic growth of these minerals and the similar growth of garnet and hornblende, new minerals genetically connected with pegmatite appear not to have formed in the wall rocks, so far as could be determined by careful megascopic examinations. Moreover, analysis of a few samples of muscovite and biotite, segregated from the rock samples, shows the presence of beryllium, tin, lithium, zinc, columbium, and cerium, as well as other elements. The minor elements of Class 2 are thought, therefore, to exist mainly within rock-forming minerals, as minor introduced elements. In the schists and gneisses, beryllium probably exists chiefly in mica, and only very scantily and irregularly in feldspar.

There remain the possibilities that the minor elements of Class 2 were introduced as a result of additive processes of a regional rather than of a localized nature, or that the elements were entirely native to the rocks before their metamorphism, but, although the evidence presented herein is to some degree inconclusive, it is thought most probable that beryllium, lithium, and

other elements of Class 2 were carried into the foliated wallrocks by solutions emanating from nearby channels of flow of pegmatitic liquors, and that the added elements were emplaced in the wallrocks largely through the entry and accommodation of their ions in the space-lattices of common rock-forming minerals, possibly by means of recrystallization of the minerals in the presence of solutions of appropriate composition. As has been noted by W. H. Newhouse [1] in another connection, geologic processes of too subtle a nature to cause the growth of additional mineral species may be expressed as changes in the composition of solid solutions.

ACKNOWLEDGMENTS.

The work was performed under the supervision of Professor W. H. Newhouse of the Massachusetts Institute of Technology, to whom the writer expresses his thanks for suggesting the beryllium project and for many apt criticisms. R. F. Jarrell and A. J. Jehle rendered valuable assistance in the analytical work. The project, of which this paper presents a part, was supported by a fellowship in the above-mentioned school.

ECONOMIC GEOLOGY LABORATORY,
MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
CAMBRIDGE, MASSACHUSETTS,
August 12, 1944.

[1] Newhouse, W. H.: Spectrographic Studies of Minor Elements in Minerals. Carnegie Institution of Washington Yearbook No. 40, for 1940–1941, p. 144, Dec. 12, 1941.

AN OCCURRENCE OF CASSITERITE AT DUBLIN GULCH, YUKON TERRITORY.

R. M. THOMPSON.[1]

ABSTRACT.

Occurrences of cassiterite are rare in Western Canada. The following brief description of a discovery at Dublin Gulch, Yukon Territory, is of interest because placer mining was carried on in this area for over forty years before cassiterite was recognized in placer concentrates in 1940, and eventually found in place in 1943.

This showing at Dublin Gulch, although possessing many features in common with other tin occurrences, differs in some respects.

LOCATION AND HISTORY.

DUBLIN GULCH is a stream nearly four miles long, running westward into Haggart Creek, a tributary of McQuesten River in the Mayo Mining District, Yukon (Fig. 1). The locality is connected to the town of Mayo on Stewart River by 43 miles of motor road.

Placer gold was discovered in the Gulch in 1898, and has been mined there from time to time ever since. Placer mining revealed the presence of a heavy white sand, determined by J. Keele in 1904 [2] to be scheelite. This drew attention to the area both in the last war, and this war, as a source of tungsten.

In 1940 cassiterite was first recognized among the heavy pebbles recovered from the placer mining, and its source was found in August, 1943, after an intensive search by Messrs. E. R. Sheppard and H. Ray for Mining Corporation of Canada, on the hill about one mile northeast of the mouth of Dublin Gulch.

PLACER OCCURRENCE.

In 1940, Mr. V. Lunde, placer mining on Dublin Gulch, picked out a number of dirty light brown and green pebbles which were notably heavy, and stayed in the sluice boxes as easily as scheelite. He believed them to be cassiterite, and this was subsequently verified by the Geological Survey. This was the first certain knowledge of cassiterite in the Gulch. Once the cassiterite pebbles had been spotted, they were found in abundance, some being as large as 2.5 pounds. These pebbles are necessarily rich ore, assaying 50 per cent tin or more, or they would not be caught by the sluice boxes. They are somewhat rounded and waterworn, and consist of angular fragments of quartzite, quartz mica schist and vein quartz embedded in chlorite, cassiterite

[1] The writer is indebted to the Geological Survey of Canada for the field information and specimens gathered in September, 1943, while on the party of Dr. H. S. Bostock. For permission to publish the results he is also indebted to the National Research Council of Canada, under whose ægis the mineralogical study was made.

[2] Keele, J.: Canada Geol. Surv., Summ. Rept., 1904, p. 38.

and tourmaline. On fresh fractures some show slickensided surfaces. The cassiterite is typically resinous, yellow to brown in color, and finely crystalline. Where rich in cassiterite, the freshly broken pebbles have the appearance of brown sugar. In addition to these larger pebbles, a considerable quantity of cassiterite is caught as small crystals in the boxes with the other heavy minerals. These grains vary in size from several microns up to a maximum of two millimeters.

The cassiterite has been found in the lower part of Dublin Gulch and on

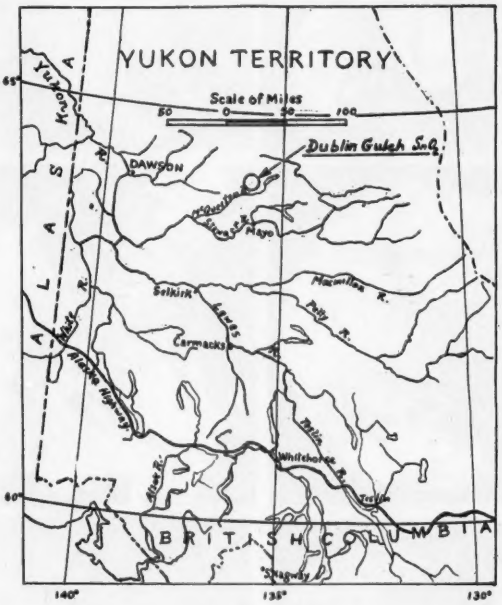
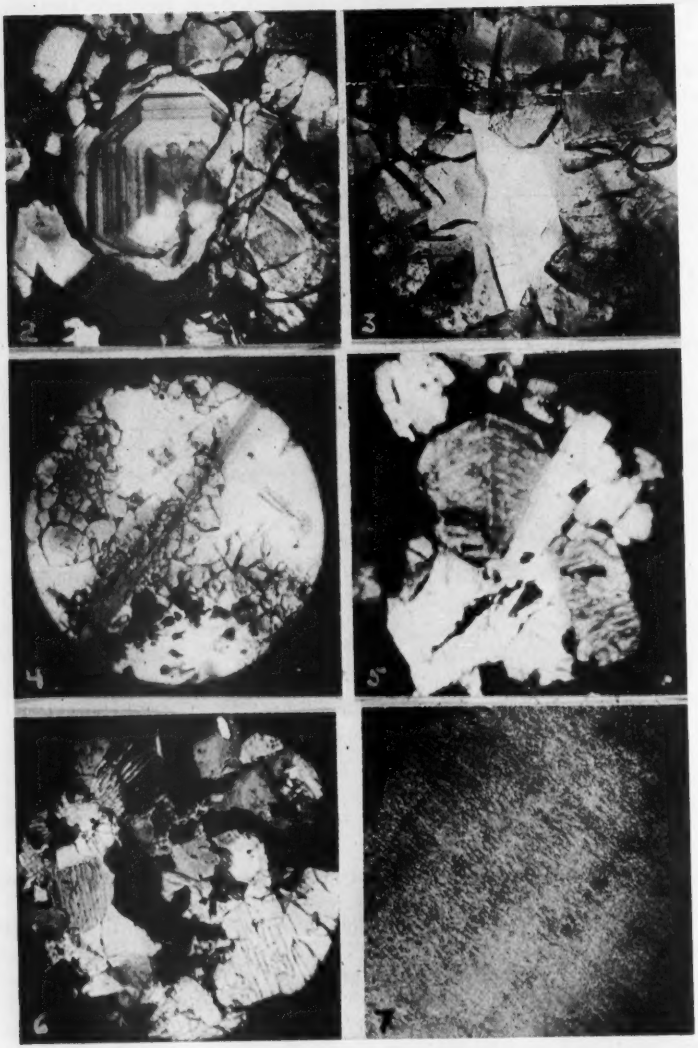


FIG. 1.

Haggart Creek. None has been found in the upper placer workings above the lode discovery.

The scheelite in the placers evidently originates in pegmatites, quartz veins, and contact metamorphic deposits associated with a granodiorite stock which extends across the head of the gulch and along its south side. Cassiterite has not been detected in these deposits, in pebbles containing the tungsten minerals, or in the tributary gulches other than that below the discovery mentioned, and in Haggart Creek from just above the mouth of Dublin Gulch.

Samples of placer gold collected from the Gulch were spectrographically analyzed, and tin was found to be a consistent minor constituent of the gold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and strongly suggests that the tin and gold are genetically related. Specimens of the granodiorite also analyzed spectrographically were found to be stanniferous.

LODE OCCURRENCE.

The country rocks on the hill where the discovery was made are quartzites and dark grey quartz mica schist probably of Precambrian age. The nearest outcrops of the granodiorite stock are about a mile away. The hill is covered by a thick mantle of soil; no outcrops are present, and no evidence of glaciation was found on it. The cassiterite was discovered on it by most painstaking panning of samples of the soil. This work revealed a zone approximately 800 feet long, and at least 200 feet wide in places, extending northwesterly over the top of the hill. Scattered tests beyond this zone suggest that it may continue over into the valley of Upper Haggart Creek. The zone strikes approximately northwest and was not traced down to Dublin Gulch itself. No cassiterite was found along the strike on the opposite side of the Gulch.

In September surface stripping by a bulldozer across the zone on the southeast face of the hill near the top at an elevation of 3,400 and 600 feet above the bottom of the Gulch revealed an inner zone of dark green soil and rock 8 to 10 feet deep in the overburden. The stripping did not actually reach solid bedrock but it showed in the lower part of the cuts loose rock fragments heaved, but still lying in related positions apparently within one or two feet of solid material. The boundaries of the inner zone are indefinite, but it is about 3 feet wide where best exposed. Only this one place was closely examined, and sampled, though the same green zone was discernible in a cut 50 feet farther down the hill.

The fragments of rock in the inner zone are dark green and brown. They are themselves made up of numerous angular fragments of vein quartz, quartzite, and quartz mica schist packed in with chlorite, tourmaline, vein quartz, limonite, and a little pyrite. The material shows evidence of extreme brecciation. Cellular limonite forms a good deal of some rock fragments. Fine green tourmaline is conspicuously abundant. Tourmalinized fragments of quartzite and schist make up the greater part of some specimens, the

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FIG. 2. Color banding in cassiterite crystal. Thin section, × 40. Dublin Gulch.

FIG. 3. Twinned cassiterite crystals surrounding quartz. (Note inclusions of hair-like rutile (?) in the cassiterite.) Thin section, × 40. Dublin Gulch.

FIG. 4. Tourmaline crystal cutting cassiterite and quartz. Thin section, × 33. Dublin Gulch.

FIG. 5. Tourmaline crystal cutting twinned cassiterite. Thin section, crossed nicols, × 120. Dublin Gulch.

FIG. 6. Aggregate of cassiterite crystals. Thin section, crossed nicols, × 35. Dublin Gulch.

FIG. 7. Thin section of Dawson wood tin pebble. Note shadowy outline of cassiterite crystals developed at right angles to the concentric color banding. Crossed nicols, × 35.

cementing material in this case being fine-grained brown and green tourmaline. Lenses of tourmaline up to three inches long and one-half inch wide consist of aggregates of finely crystalline hairs, none of which are more than three-sixteenths of an inch long. Fine powdery soil around the fragments of rock is a mass of fine tourmaline.

Cassiterite, seldom readily recognizable to the naked eye, may be seen as small patches or nests, and as disseminated crystals in a few fragments, but it can be panned from the loose material anywhere in the zone.

A channel sample across it taken by the writer and assayed in Vancouver contained 1.53 per cent tin. Two other samples, assayed by the Bureau of Mines at Ottawa, contained 1.53 and 0.83 per cent tin, with a trace of gold and 0.04 ounces of silver per ton for both samples.

MICROSCOPIC STUDY.

Cassiterite. Cassiterite is the only tin-bearing mineral in the ore. In thin section it is yellow to yellowish-brown, with pronounced color banding (Figs. 2–7). Individual crystals measure up to a millimeter across. Aggregates of subhedral to euhedral crystals with inclusions of hair-like tourmaline are common. Geniculated, contact, and penetration twins are present. Colloform and needle tin are absent. A considerable amount of the cassiterite is crowded with inclusions of a colorless to black, hair-like mineral which averages about two by twenty microns in size. This mineral was optically indeterminable, but is believed to be a titanium mineral, possibly rutile, as a spectrographic analysis of purest obtainable cassiterite showed among other elements the presence of a small amount of titanium.

Quartz. The quartz is colorless and clear, occurring as anhedral grains up to one-quarter of an inch, and also as aggregates of small grains a few microns in size. Small euhedral crystals often occur in a matrix of limonite. Several crystals were noted to contain inclusions of tourmaline needles up to 0.10 mm. in length.

Tourmaline. The tourmaline varies in color from pale tan to blue green to brown. It occurs as needles, rosettes, and fibrous aggregates, most of which are stained with limonite. Trigonal cross-sections are common. The tourmaline appears to be late, cutting chlorite, quartz, and cassiterite.

Chlorite. Chlorite was not recognized in the sections examined, but is of common occurrence in the ore.

Pyrite. Pyrite was recognized in only one section, its color and outline being characteristic. It occurs in small amounts in the ore, but the abundant limonite indicates it to be common in unoxidized portions of the deposit.

Limonite. All minerals present in thin section are more or less heavily stained by limonite. It also occurs as irregular masses and thin veinlets. In hand specimens, cellular limonite is locally abundant.

The following order of crystallization of the minerals present is suggested: chlorite, quartz, cassiterite, tourmaline, pyrite, and limonite. The mineral association is indicative of a deposit of the high temperature type. Some of the more common associates of cassiterite, such as topaz, feldspar, and fluorite, were not detected in the sections studied.

It is interesting to note the absence of tin mineralization in the intrusive itself, although it is believed to be the source of the cassiterite. The nearest intrusive outcrops occur approximately one mile to the south and to the east of the showing. The evidence available suggests that the tin deposit may be a fault breccia.

OTHER LOCALITIES.

In the last few years cassiterite has been identified in black sands from several other creeks in the Mayo district. In all cases the cassiterite is well crystallized and occurs in grains from a fraction of a millimeter up to tetragonal crystals one-half inch long.

Placer tin pebbles of unknown origin have been, and are being picked up by dredges in the vicinity of Dawson. The quantity is not large, amounting to only several hundred pounds per year, which is given to tourists as "Alaska Black Diamonds." These pebbles are dark brown to black in color, extremely hard and smooth. They exhibit banding and colloform structures suggestive of colloidal deposition and are referred to as wood tin pebbles.

SUGGESTIONS FOR PROSPECTING.

In the light of the above evidence, all shear and fault zones carrying tourmaline, whether in sedimentary or igneous rocks, should be carefully examined for cassiterite.

Shear zones at the Sullivan mine contain cassiterite and tourmaline.[3] Small amounts of tourmaline have been noted in a quartz vein at the Cariboo Gold Quartz mine. No cassiterite has been identified here, but small amounts of tin are indicated spectrographically in the galena and sphalerite.

Tourmaline appears to be the most persistent associate of cassiterite in Western Canada.

ACKNOWLEDGMENTS.

The work was done in the Geological Laboratories of the Department of Geology, University of British Columbia, under the direction of Dr. H. V. Warren, who with Dr. H. S. Bostock offered many constructive criticisms and assisted the writer in the preparation of this report: to both the author tenders his thanks.

[3] Pentland, A. G.: The occurrence of tin at the Sullivan Mine. The Miner, August, 1943, p. 42.

DISCUSSION AND COMMUNICATIONS

THE PORCUPINE PORPHYRIES.

Sir: The twin questions: (1) What is the age of the porphyry bodies in the Porcupine district of Ontario?, and (2) What do the porphyry contacts mean in terms of the mechanics of porphyry intrusion? have been recently revived by the article "Some Porphyry-Sediment Contacts at the Dome Mine, Ontario," in the March–April 1944 issue of ECONOMIC GEOLOGY by Terence C. Holmes, by the article "Scheelite Veins Related to Porphyry Intrusives, Hollinger Mine," by C. C. Allen and R. G. Folinsbee in the August issue, and by the further discussion, "Replacement and Igneous Intrusion," by J. A. Reid in the September–October issue.

Reid concludes: "It would seem a reasonable assumption to consider that the whole range of igneous phenomena, from true igneous fusion at one end to hydrothermal activity at the other, when looked at in a broad way, can be regarded as a continuous process without necessarily any definite breaks along the course, and that given favorable circumstances or conditions, a concentrated solution or emanation from the lower part of the hydrothermal zone, heavily charged with rockmaking constituents, may produce the same result by replacement that is ordinarily ascribed to emplacement by igneous intrusion." Although I subscribe to Reid's conclusion (with a mental question mark after the word "concentrated") and although I have mapped much granitized sedimentary rock, I do not believe, as Holmes does, that the porphyry contacts in and near the Dome mine contribute valid evidence of replacement of sedimentary rock by igneous rock. My first reaction on reading Holmes's paper and the paper by Allen and Folinsbee, although I disagree with the conclusions, was to hold my peace until I again had the facilities and time to make a more complete reply. Rather, however, than confuse the issue further by a silence that might imply that there was no disagreement with such conclusions, I have decided to register my vote on some of the issues involved.

The following does not pretend to be a full discussion of the problem. Neither notes nor maps nor articles * on the district which would be necessary for such a discussion are available to me at the present time. It is rather a plea for openmindedness on this subject, a partial restatement of the chief reasons for a skepticism regarding the conclusions of Holmes, Allen, Folinsbee and the majority of geologists who have published papers on the Porcupine porphyries, which skepticism, however, is shared by a respectably large minority. My opinions concerning the porphyries are based on four years' intensive study of the Hollinger mine † and two years in charge of a geological

* The titles, volume and page numbers, and other details in my list of references have been copied from the articles by Holmes, Allen and Folinsbee, and Reid.

† During two of these years as member of L. C. Graton's staff.

study of the Porcupine district which included detailed remapping and structural analysis of the surface exposures. During this work practically all of the surface exposures of igneous contacts in the district as well as porphyry contacts in all of the mines of the district were examined.

Much confusion as to the age of the porphyries arises from the fact that there are at least two and probably three ages of porphyry, all very similar in appearance.

The result has sometimes been that evidence obtained from a porphyry body of one age has been accepted as proof of the age of other porphyry bodies of a different age.

There is unquestionably Keewatin porphyry.

The great mass of fragmental porphyry in the vicinity of Gold Center and the Vipond mine prior to the paper by Graton, McKinstry, and others (2) had been considered to be Algoman in age. In that paper it was first recognized that the porphyry mass (which in fact includes pieces of iron formation, greywacke, and lava) is a Pre-Timiskaming agglomerate occupying a stratigraphical position between the Keewatin lava and the overlying Keewatin and Timiskaming sedimentary rocks. It is now so recognized by the Ontario Bureau of Mines (4).

Porphyry pebbles in the Keewatin and Timiskaming conglomerates are further indisputable evidence of Keewatin porphyry.

There is unquestionably Algoman, or at least post-folding porphyry.

Such porphyry is most abundant in the south half of the area covered by Hurst's map (4). The porphyry is blocky and undeformed except where sheared very locally by later faults. It has sharp chilled contacts with its host rock. Dikes of this rock notably cut across folds in the older rock without attempting to follow flow or sedimentary contacts. The rock outlines are generally straight or sharply angular and do not simulate folds. The rock is often very fresh but may be severely altered by hydrothermal solution in which event it is sericitized and heavily impregnated with ankerite.

Such porphyry belongs to an igneous complex including intrusives of much more basic rock resembling diorites in appearance.

The porphyry bodies about which there is controversy including the Millerton, Miller Lake, and Pearl Lake bodies, intrusive facies of the Crown mass, and the porphyry bodies in the Coniaurum, Dome, and Preston East Dome mines present only inconclusive and circumstantial evidence regarding their age; and some of that is apparently contradictory. (All in fact may not be the same age.)

The close spatial relationship of veins and highly ankeritized wallrock to porphyry bodies suggests to some, including Allen and Folinsbee, a genetic relationship. To others, including myself, it suggests that the porphyry bodies acted like knots in the structure around which fracturing, vein emplacement, and consequently hydrothermal alteration were most intense.

The following observations suggest that these porphyry bodies are at least earlier than all of the folding: *

* Relatively recent discoveries of important orebodies in conglomerate (e.g. Pamour Mine) indicate that the spatial association of ore with porphyry is not as close as formerly supposed.

1. In striking contrast to the porphyries of unquestionably Algoman age previously described, their contacts have repeated sinuous indentations that resemble in shape and size the minor folds in other contacts.

2. Most of these porphyry bodies have been schisted, especially at their margins, and such schistosity is parallel to the axial planes of the folds. In general these porphyry bodies show about the same degree of deformation as their host rocks of comparable competence. (Similar schisted quartz porphyries in some areas in Quebec have long been regarded as Keewatin.)

3. The long axes of these porphyry bodies are parallel not only to the pitch of the folds, but also to the elongation (up to 10 to 1) of porphyry pebbles in the conglomerates and of amygdules and spherules in the lavas.

4. Careful mapping reveals lines of detached fragments up to several feet in diameter of porphyry in sheared lavas at porphyry contacts, such fragments apparently being portions of porphyry apophyses that were pulled apart during deformation.

5. Porphyry in the Dome mine, although adjacent to the sediments over a great distance, had nowhere (up to 1941 anyway) been found to cross the Keewatin lava–Timiskaming contact or to be in definite intrusive relationship with the Timiskaming sediments.* The porphyry bodies, moreover, curve in sympathy with folds in the other rocks.

6. These porphyry bodies are cut by long straight post-folding, non-schisted, *but pre-mineralization* albitite dikes of presumably Algoman age.

7. The fact, however, that these porphyry bodies although themselves folded nevertheless locally appear to transgress axial planes in the folds in the lavas suggests that these porphyry bodies may be younger than the earliest folding, although I am not certain that irregularly cross-cutting porphyry stocks or sills caught in severe folding would not result in the shapes now apparent.

My guess is that these porphyries were intruded either before Keewatin folding or else after Keewatin folding but before Timiskaming folding. If the latter is the case, the feeders for the Keewatin agglomerate have never been found.

With specific regard to Holmes's paper, Holmes states, "At several places rocks are found along their (i.e. porphyry) contacts which have the general appearance of porphyry except for numerous, more or less, faint outlines which resemble the pebbles in the Timiskaming conglomerate. It is the writer's (i.e. Holmes's) opinion that these faint outlines represent pebbles in a conglomerate which has been altered by solutions emanating from a magma to a rock which resembles in some degree the porphyry bodies of the mine." Whitman (6) as pointed out by Reid (6) arrived at a similar conclusion in 1927 with respect to the fragmental porphyries of the district. The picture is clearly one of an intensely hydrothermally altered zone in which there appear to be "shadows" of former porphyry pebbles or fragments. Holmes has concluded, like Whitman, that this phenomenon is due to igneous replacement.

Graton, McKinstry and Others (2) have already shown that Whitman

* Between 1930 and 1941 I have found a succession of Dome geologists very much divided on the question as to whether the porphyry is pre-Timiskaming or post-Timiskaming.

mistook porphyry agglomerate for porphyry "école injection" and that other types of porphyry fragments contained in the lavas near porphyry contacts in the Hollinger mine are clearly due to the pulling apart of small porphyry dikes and apophyses during post-intrusion deformation. I am strongly inclined to believe that this is the explanation of the phenomena described by Holmes, if indeed he is not describing true conglomerate.

Locally intense hydrothermal alteration in the Porcupine district renders rocks unrecognizable and obscures their fundamental character. In rocks as hydrothermally altered as some of those described by Holmes (3), the original character would be difficult to determine. Consider, for example, the following descriptive statements by Holmes. (The italics are mine.)

P. 135: "The great bulk of the rock (i.e. porphyry) is too fine-grained to be positively identified in hand specimens, but sericite, acid feldspar and carbonate are possibly important; *some appears to be highly carbonated. Schistosity is found almost everywhere. . . .*"

P. 137: "As a rule these shadow pebbles occur in small areas, separated by *normal sericite schist or porphyry* in which no suggestion of pebbles can be found. . . . They do not usually extend more than twenty-five feet from undoubted sediments. The size and spacing of the shadow pebbles would resemble the pattern of the conglomerate if the small interstitial pebbles and a few of the larger pebbles were removed from it."

P. 140: "The writer has seen no porphyry in the mine except that described from near the 'Carbonate Rock' sufficiently different from that within the shadow pebble zones to suggest that the genesis is radically different. However, it must be pointed that *all of the rocks under consideration have been intensely sheared and altered and this may have obscured the differences.*"

P. 137: In describing the place where undoubted conglomerate occurred against porphyry, "The impression gained at the time was that the porphyry graded into conglomerate in about fifteen feet." On the other hand it can be argued that both the porphyry in the conglomerate and the arkosic material resembling porphyry just north of the Dome mine may have been derived from erosion of the main porphyry bodies as first suggested by Murphy (former Dome geologist) and adopted as a tentative possibility by Graton, McKinstry, et al. (2).

The point made by Holmes that the porphyry in the conglomerate is fresh whereas the intrusive porphyry is altered appears to me to have no bearing on this question inasmuch as the hydrothermal alteration of the district is very clearly later than both the conglomerate and the porphyry bodies. (There is both relatively fresh porphyry and highly altered conglomerate near the Dome mine.)

It will require a very thorough field and laboratory study by an able and experienced man or team of men to solve the complexities of the Porcupine porphyries. There is danger in arriving at an oversimplified answer through failure to see all of the evidence.

For instance, the question of fragmental porphyry in the district is further complicated by the presence of breccia dikes containing porphyry fragments. These are well exposed on the surface of the Coniaurum mine and in the

McIntyre mine. Like the albitite dikes and some of the other porphyries in the district these are probably Algoman in age.

The igneous and structural histories of the district are more complex than is perhaps generally recognized, and I believe the answers to the questions of the age and their mode of emplacement of the porphyries are not to be found in any one mine or any one small area of outcrops.

It is hoped that this discussion will have served to keep these questions open to critical enquiry at least until both the petrographic and structural evidence of the district are brought together in a competent and comprehensive way for balanced judgment.

J. K. GUSTAFSON.

MAGMA COPPER COMPANY,
SUPERIOR, ARIZONA,
February 1, 1945.

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REVIEWS *

Volcanoes as Landscape Forms. By C. A. Cotton. Pp. 416; Figs. 223. Whitcombe and Tombs Ltd., Christchurch, New Zealand, 1944. Price, 32/6d.

Professor Cotton has added a new volume to his current list of "best-sellers." Here in a single book has been placed a wealth of information covering an important, fascinating subject. The extent of source material, together with the author's lucid descriptions, his carefully selected photographs and excellent line sketches make this one of the most important contributions to volcanology and to geomorphology to appear in recent years. C. A. Cotton continues to place New Zealand on the geomorphic map.

"An approach to volcanism may be made through either petrology or geomorphology. . . . In this book, after a few introductory chapters, the latter approach is adopted, and the book is frankly concerned with landforms of volcanic origin and their geomorphic development rather than with theories of volcanism and petrogenesis." The 70-page Part I, The Mechanism of Volcanism, is an excellent review of much of the literature of volcanology. The fourfold classification of eruptive activity of Lacroix is discussed but discarded in favor of a twofold classification (lava and pumice volcanoes) based on explosivity, in turn based on chemical character of associated magma. Cotton follows Jagger in the latter's explanation for the liquidity and high temperature of surface lava. The mobile, spongy surface lava—pyromagma—with its expanding gas content is distinguished from the deeper, relatively very immobile hypomagma in which reagent gases are in solution. The high surface heat is regarded a result of gas reactions involving the distinct gases released from solution. The reader not thoroughly acquainted with volcanologic nomenclature may become somewhat involved with the multiplicity of terms and wish for a glossary.

In Part II, Volcanic Landscapes, the author discusses: basaltic lava domes and cones, lava plateaus, lava fields, aa and block lava, coulees and tholoids, ash showers and nuees ardentes, ash-built and stratified cones, maars and tuff rings, meteor craters, submarine eruptions, pillow lava, craters and calderas, dissected basalt and ignimbrite plateaus, and erosion and destruction of volcanic mountains. Two pages on volcanic contributions to the atmosphere and the ocean have been appended.

Professor Cotton refuses to accept the shield volcano type as a structure made up of nearly horizontal flows of progressively dwindling diameter; he contends that all lava piles of central contruction will exhibit some concavity in their flank profile. Some terms, as "rifts," "rents," and "coulees," have had such a variety of uses in the literature that they might well be omitted in new writings. Cotton is clear in his use of these terms. He is not clear, however, in his conception of ring dikes as compared with cone sheets. The book is quite free of typographical errors. A few omissions, as in the equation on page 19 and the explanation of figure 124, were noted.

Ralph E. Digman.

* Books noted under *Reviews* and *Books Received* may be ordered through the Economic Geology Bookshop, M. M. Leighton, Urbana, Ill., but orders for official reports and single copies of Journals should be sent directly to their publishers.

The Migration and Accumulation of Petroleum and Natural Gas. By F. M. VAN TUYL, B. H. PARKER AND W. W. SKEETERS. Pp. 111; Figs. 4. Vol. 40, No. 1, Quarterly of the Colorado School of Mines, Golden, 1945. Price, $1.50.

Ever since I. C. White publicized the theory of anticlinal accumulation of oil and natural gas, geologists have been interested in the problems dealing with the movement of petroleum substances from the strata of their origin and, as well, movement within reservoir beds. The solution of these problems may be of more than academic interest, for adequate understanding of the nature of petroleum movements could lead to more scientific exploration procedure. The problems of migration and accumulation introduce other problems chief of which are: time of movement, nature of hydrocarbons during movement, condition of enclosing strata at time of petroleum migration, and indeed, origin of petroleum.

Van Tuyl and Parker have been conducting investigations and leading discussions relative to the major problem of migration and accumulation. Some of this has been sponsored by the Research Committee of the American Association of Petroleum Geologists. The present work, published as a Quarterly of the Colorado School of Mines represents the culmination of their investigations. The paper is largely a review of the problem and ". . . makes no claim for the solution of this baffling question. It represents rather an attempt to coordinate and analyze the known data and to weigh the current theories. Suggestions are also offered for further investigations. . . ." Numerous field examples are cited and laboratory experiments are critically analyzed.

This paper is a thorough survey of the problem. Statements from a vast literature, which has been well combed, and opinions elicited from numerous petroleum geologists make this report one of the most concerted to date. The three principal divisions of the paper are: extent and character of migration, analysis of the problem, and mode of migration and accumulation. The theories of migration that are discussed are: anticlinal, hydraulic, gravitational-hydraulic, compaction, propulsive-force-of-gas, screening, cementation, capillary and replacement. A five-page list of references concludes the work. This number of the *Quarterly* is an important contribution to petroleum geology.

R. E. D.

BOOKS RECEIVED.

RALPH E. DIGMAN.

Historical Geology—The Geologic History of North America. By RUSSELL C. HUSSEY. Pp. ix + 491; Figs. 344. McGraw-Hill, New York, 1944. Price, $3.50.

Diatomites of the Pacific Northwest as Filter-aids. K. G. SKINNER, ET AL. Pp. 87; Figs. 44. Bull. 460, U. S. Bureau of Mines, Washington, 1944. Price, 25 cents.

Coal-Mine Accidents in the United States: 1942. W. E. ADAMS AND L. E. GEYER. Pp. 140; Fig. 1. Bull. 462, U. S. Bureau of Mines, Washington, 1944.

Low-Temperature Carbonization of Alaskan Coals. W. A. SELVIG, ET AL. Pp. 16. Tech. Paper 668, U. S. Bureau of Mines, Washington, 1944. Price, 10 cents.

Rates of Sediment Production in Southwestern United States. C. B. BROWN. Pp. 40. U. S. Soil Conservation Service, Washington, 1945.

Illinois Clays and Shales as Mortar Mix. R. K. HURSH, ET AL. Pp. 55; Figs. 12. Report of Investigations, No. 100, Illinois Geol. Survey, Urbana, 1944.

Cheilotrypid Bryozoans from Pennsylvania and Permian Rocks of the Mid-continent Region. R. C. MOORE AND R. M. DUDLEY. Pp. 407; Pls. 48. Bull. 7, Part 6, Kansas Geol. Survey, Lawrence, 1944.

Pennsylvania Morrowan Rocks and Fusulinids of Kansas. M. L. THOMPSON. Pp. 431; Figs. 2; Pls. 2. Bull. 52, Part 7, Kansas Geol. Survey, Lawrence, 1944.

Summary of Records of Surface Waters of Maryland and the Potomac River Basin, 1892–1943. Pp. 296. Bull. 1, Maryland Geol. Survey, Baltimore, 1944. Cloth bound.

Mineral Resources of Missouri. Map, colored. 38 in. × 34 in. Scale, 1 in. = 10 mi. Missouri Geol. Survey, 1944.

Twenty-third Biennial Report. W. M. LAIRD. Pp. 10. North Dakota Geol. Survey, Grand Forks, 1944.

Stratigraphy and Structure of North Dakota. W. M. LAIRD. Pp. 6, Figs. 5. Bull. 18, North Dakota Geol. Survey, Grand Forks, 1944.

Water in Ohio. W. STOUT, ET AL. Pp. 672; Maps 8. Bull. 44, Ohio Geol. Survey, Columbus, 1943. Cloth bound.

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A Quarter Century of Progress. G. H. ASHLEY. Pp. 10; Figs. 10. Pennsylvania Dept. of Internal Affairs, Harrisburg, 1944.

Case Histories and Quantitative Calculations in Gravimetric Prospecting. D. C. BARTON AND P. WEAVER. Pp. 49; Figs. 27. Tech. Pub. 1760, Am. Inst. of Min. and Met. Eng., New York, 1944.

The Interpretation of Earth-Resistivity Measurements. M. MUSKAT. Pp. 7; Figs. 4. Tech. Pub. 1761, Am. Inst. of Min. and Met. Eng., New York, 1944.

Titanferous Magnetite Deposits of the Lake Sanford Area, New York. R. C. STEPHENSON. Pp. 25; Figs. 19. Tech. Pub. 1789, Am. Inst. of Min. and Met. Eng., New York, 1945.

The following papers, reprinted from Industrial Diamond Review, are available, free of charge, from the Editor, Industrial Diamond Review, 226 Latymer Court, Hammersmith, London, W. 6: **Diamond Geometry.** PAUL GRODZINSKI. Pp. 5; Figs. 8. **Time and Rate Fixing on Grinding Wheel Truing.** F. L. MEYENBERG. Pp. 3; Figs. 2. **Germany's Effort to Meet its Shortage in Industrial Diamonds.** Pp. 12; Figs. 14. **Jewel Bearings in Watches and Instruments.** Pp. 3; Fig. 1. **Properties of Hard Abrasives.** Pp. 2. **The Control of Quality of Abrasive Wheels by X-ray Inspection.** M. TERMINASOV AND L. KHARSON. Pp. 4; Figs. 4. **The Microphotography of Diamond and Sapphire Surfaces.** J. F. KAYSER. Pp. 4; Figs. 10. **Diamond Dust is not Injurious to the Lungs.** Pp. 1. **Recommendations for the Use of Diamond Turning Tools.** Pp. 2; Figs. 9. **The Care and Use of Diamond Truing Tools.** Pp. 2; Figs. 14.

SOCIETY OF ECONOMIC GEOLOGISTS

At the Annual Business Meeting of the Council, held in New York City on February 20 at the Men's Faculty Club, Columbia University, and the Annual Business Meeting of the Society, held on the same date at the Harvard Club, the following business was transacted.

At the Council Meeting in the forenoon and afternoon, reports by Retiring President Boutwell, by the Secretary and by the Treasurer, and by the various Committee Chairmen were presented. The personnel of the standing committees for the new year was discussed. Problems related to the Annotated Bibliography of Economic Geology, the award of the Penrose Medal, the revision of certain by-laws, and especially the financial status of the Society and the proposed Geological Institute of America were discussed at length. As regards the Geological Institute, it was decided to give the proposal further study, and appointment of a continuing committee designed for that purpose was authorized. The following new officers were declared elected:

For President-Elect (taking office in 1946): W. O. Hotchkiss

For First Vice-President-Elect (taking office in 1946): J. Terry Duce

For Regional Vice-Presidents (taking office in 1945):

Alfred Brammall, Europe
M. J. S. Krishnan, Asia
Rene A. Pelletier, Africa
George Hanson, North America
O. H. Leonardos, South America
Robert L. Jack, Australia

For Councilor (1945–1948):

Francis Cameron
George M. Fowler
Thomas G. Moore

The following new members were declared elected:

Jorge A. Broggi
John Weston Butler
Robert Roy Coats
John J. Collins
H. C. Alves De Souza
Herman Gunther
John Charles Maher
Robert Stevens Moehlman
Selden Spencer Nye
Franklin Gray Pardee
John Payne, Jr.
Benjamin Martin Shaub
Ralph E. Van Alstine
L. Kenneth Wilson

Robert G. Yates

The date of the next meeting is held in abeyance pending the further development of the war.

The evening meeting at the Harvard Club was attended by forty-four members and guests, of which about half were non-residents of New York City. A brief report of the past year's work was given by the officers of the Society. This was

followed by announcement of the newly-elected officers and members. The new officers were inducted and President Oscar E. Meinzer took the chair. There followed a stimulating and thoughtful address entitled "Economic Geology" by the Retiring President, John M. Boutwell; this dealt with the history of the development of the profession of mining geology in the United States, the training now required for the profession and its prospective use and development in the future.

CHAS. H. BEHRE, JR., *Secretary.*

February 23, 1945.

REGINALD CHARLES WILSON.

1888–1943.

Reginald Charles Wilson was born in 1888 in Melbourne, Victoria, Australia and educated at Scotch College and the Melbourne University, graduating B.Sc. in December 1910 with geology as his major subject. He immediately left Australia for service in tropical Africa, returning only for one short visit during the rest of his life. His first job was as assistant to E. O. Thiele (afterwards Sir Edmund Teale) in a mineral survey of the territory in Portuguese East Africa controlled and administered by the Companhia di Mozambique. This survey ceased with the outbreak of the 1914–18 war and Wilson returned to England and received a Commission in the Royal Welch Fusiliers early in 1915. He served throughout the war, being wounded in the Battle of the Somme in 1916, and after a period in 1917 as Captain in the Royal Engineers he returned to his old regiment.

With the formation of a Geological Survey of Nigeria in 1919 the Colonial Office appointed him as assistant to Dr. J. D. Falconer, the first Director. At that time the practice was to spend seven months on tour in Nigeria and the remaining part of the year in England. Later in 1932 the tour was extended to 18 months in two years. Wilson's first charge was the geological exploration of a belt of country in Southern Nigeria along the Western Railway. This work was carried out under considerable difficulty owing to the densely forested character of much of the country and his initiative and ability to make the best of circumstances greatly availed him. It resulted in the first attempt at a detailed study of the gneisses and schists of the crystalline basement of West Africa and also in the recognition of much of the coastal fringe as of Eocene Age. From 1922–24 he undertook the geological exploration of a similar strip along the Eastern Railway and the investigation pioneered the systematic unravelling of the Cretaceous and Tertiary deposits of South Eastern Nigeria in addition to making discoveries of coal, lignite, pottery and brick clays. This was followed by a study of the Brown Coals and a two months reconnaissance of part of the Mamfe Division of the Cameroons Province. In 1926 he was awarded the D.Sc. degree at the Melbourne University and in January 1927 he was appointed Director in succession to Dr. Falconer.

As Director, Wilson was eminently successful. Under his direction the Survey expanded and its headquarters were removed from Lokoja to Kaduna in 1930, a geological museum set up for educational purposes and a large amount of useful work on underground water supplies was carried out. Wilson was a quiet, unostentatious and efficient worker and his happy and friendly disposition, his tactful handling of diverse problems gave him a command over men and situations which more aggressive qualities would have denied him. He died at his post in Nigeria on May 7, 1943.

FRANK L. STILLWELL.

JOSEPH ELLIS THOMSON.

The sudden death of Ellis Thomson, on September 26, 1944, from a cerebral hemorrhage, came as a great shock to his many friends.

Joseph Ellis Thomson was born in Toronto, in 1882, and in 1907 graduated from the University of Toronto in Mining Engineering. Following graduation he pursued graduate studies for short periods, previous to 1914, at Columbia University, the Sächsische Bergakademie in Freiberg, and the University of Heidelberg. Obtaining leave of absence from the University of Toronto, in 1929, he spent a year at Harvard University, specializing on mineralography, and received the degree of Ph.D.

Thomson's field work comprised work with the Sterling Coal Company of West Virginia, the Crow's Nest Coal Company in British Columbia, three summers with the Ontario Department of Mines and several with the Canada Geological Survey. He joined the staff in Mineralogy, University of Toronto, in 1912, as a Demonstrator and was later promoted, finally, in 1944, head of the Department. About fifty papers, most of which involved mineralographic studies were published and he had a considerable private practice in the microscopic examination of ores and petrographic specimens for companies and individuals and in later years abandoned field work entirely.

Professor Thomson took a very active interest in clubs and societies, technical and otherwise. He was a charter fellow of the Mineralogical Society of America, councillor, vice-president and finally president (1938). He served the Toronto Branch of the Canadian Institute of Mining and Metallurgy as secretary for three years and chairman for one. He rendered conspicuous service to the Royal Canadian Institute as secretary and vice-president each for four years, and president for three years. He also served as secretary-treasurer and president of the Faculty Union, and president of the Walker Mineralogical Club, University of Toronto, and as president, in 1943, of the Toronto Branch of the English Speaking Union. Much of Thomson's energy in his later years was given to societies of various kinds which demanded his services. He had a keen sense of humor and he was interested in people, and his genial disposition gained for him many friends. At times his humor was expressed in rhyme and many will remember some of his parodies at the meetings of the Mineralogical Society.

E. S. MOORE.

January 5, 1945.

SCIENTIFIC NOTES AND NEWS

J. V. N. DORR, II, chairman of the Committee for Cooperative Investigations Abroad of the U. S. Geological Survey, returned in March from a trip to Brazil.

ROBERT S. MOEHLMAN became field geologist for the South American Development Company on December 1st. This company operates mines in Ecuador and British Columbia, as well as being interested in prospects in other countries. Address: South American Development Co., 75 West Street, New York City 6.

KENNETH K. LANDES, chairman of the department of geology in the University of Michigan, has been elected president of the Mineralogical Society of America for 1945.

HUGH E. MCKINSTRY has been appointed professor of geology in Harvard University from July 1, 1945. He is now chief of the minerals division in the Foreign Development Branch of the Foreign Economic Administration. He is also chairman of the committee on mining geology of the American Institute of Mining and Metallurgical Engineers. Home address: 1499 Irving St., N.W., Washington, D. C.

JOHN W. VANDERWILT has been elected vice-president of the Rocky Mountain Association of Petroleum Geologists. His address is: Midland Savings Bldg., Denver, Colo.

RUSSELL G. WAYLAND has been promoted to major in the Corps of Engineers, U. S. Army. He is in the minerals group, materials branch of the production division of the Army Service Forces Headquarters, Washington, D. C. Home address: 602 Arlington Village, Arlington, Va.

ARTHUR B. YATES, S.D. 1931, chief geologist of the International Nickel Company, has been in South America since December.

Friends of MR. CORNELIO L. SAGUI will be pleased to hear that he is once more in correspondence with his friends abroad and that his address remains 18 Rue Luchet, Avignon, France. Mr. Sagui published several papers during the war years, chiefly in the Bulletin of the Société d'Etude des Sciences Naturelles de Vaucluse.

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